AMERICAN LUBRICANTS

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From the Standpoint of the Consumer

BY

L. B. LOCKHART
Consulting and Analytical Chemist

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PREFACE.

The purpose of this book is to aid the user and the buyer of lubricants in a more intelligent selection of oils and greases. The point of view throughout is that of the user rather than that of the refiner.

An effort has been made to include such facts and figures in regard to lubricants as will best serve to bridge the gap between the refiner or manufacturer and the consumer. Of almost equal importance, a conscientious effort has been made also to *exclude* irrelevant matter so as not to obscure the main facts.

In a book of this character it is of the utmost importance that the refiner, the seller, the buyer and the user of lubricating oils speak the same language.

The language of the American oil trade, so far as viscosity is concerned, is that of the Saybolt Universal Viscosimeter; consequently all viscosities given in this book are with this viscosimeter at 100° F. unless otherwise specified, except that the viscosity of cylinder oils is taken at 210° F. Likewise the Flash and Fire Tests are with the Cleveland (or similar) Open Cup. Unless otherwise stated, all temperatures are Fahrenheit, and the Baumé gravity is based on the Bureau of Standards scale at 60° F.

The specifications given are in all cases the latest obtainable.

The author takes this occasion to acknowledge his indebtedness, directly and indirectly, to the published data on petroleum oils which has been drawn upon freely.

He trusts that the book will prove of practical aid, especially to the buyer and the consumer of lubricants.

L. B. LOCKHART.

Atlanta, Ga., August 1, 1917.

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CHAPTER I.

CRUDE PETROLEUM.

The Shift in Production.—The American Petroleum Industry began with the sinking of the first oil well in Pennsylvania in 1859, two years after oil had been struck in Roumania. The production in the United States was confined to Pennsylvania and New York until 1876. In 1891 the Pennsylvania fields reached their maximum production of 33,009,236 barrels which was 61 per cent. of the country's production for that year. The Appalachian field as a whole reached its maximum production of 36,295,433 barrels in 1900 which was 57 per cent. of the output for that year.

In 1915 the Appalachian field produced only 22,860,048 barrels of petroleum, or 8 per cent. of the total for that year, and of this amount only 8,726,483 barrels were actually produced in Pennsylvania and New York. The estimated production for Oklahoma in 1916 was 105,000,000 barrels which is greater than the production for the whole United States for any year prior to 1907. In 1915 Oklahoma and California together produced 65 per cent. of the country's petroleum, the total for that year being 281,104,104 barrels. The above figures refer to the marketed production. The estimated actual production for 1916 was 292,300,000 barrels for the United States, of which nearly 20 per cent. was used for fuel oil.

In February, 1916, the United States Geological Survey, after an exhaustive study of the known fields in the United States, estimated that the fields are 32 per cent. exhausted. The Appalachian field is 70 per cent. exhausted. Additional statistics are given at the end of this volume (pages 223-225.)

Characteristics of Crude Petroleum.—Petroleum or crude mineral oil is a dark brown liquid made up of a mixture of compounds, some of which would be gases and solids if separated from the mixture. Small amounts of sulphur, oxygen and nitrogen are usually present.

There are two well known types of crude petroleum: (1)

Paraffin-base oil which contains much light oil or gasoline and considerable paraffin wax, like the Pennsylvania oils, and (2) asphalt-base oils which contain very little light oil, or paraffin wax, but contain much heavy, low cold test oil, like the Texas oils. A third type is also recognized, called mixed-base oil, which is intermediate between the other two types. Paraffin-base oils consist largely of compounds containing relatively more hydrogen than is present in the asphalt-base or naphthene oils.

Crude oils are valued largely on the basis of their distillation products. Oils which yield much gasoline and kerosene on simple distillation, and which are rich in paraffin, bring the highest prices at the wells, though the amount and nature of the sulphur impurities are of much importance.

Crude oils from the different fields of the United States have the following characteristics:

Oils from the Appalachian field (New York, Pennsylvania, West Virginia, Kentucky, and eastern Ohio) are mainly paraffin base, free from asphalt and objectionable sulphur, and they yield by ordinary distillation high percentages of gasoline and burning oils. The gravity ranges from 34° to 48° Bé.

Oils from the Lima-Indiana field (Indiana and northwestern Ohio) consist chiefly of paraffin hydrocarbons, though containing some asphalt, and are contaminated with sulphur compounds which require special treatment for their removal—usually with copper oxide and lead oxide. Some lubricating oil distillates are produced in this field. The Canadian oils belong to this group.

Illinois oils are of mixed asphalt and paraffin base and differ much in specific gravity and distillation products. The sulphur which is generally present can be removed without special treatment.

Mid-Continent oils (from Kansas, Oklahoma, northern and central Texas and northern Louisiana) vary in composition within wide limits, ranging from asphaltic oils poor in gasoline and kerosene, to paraffin oils of low asphalt content which yield much gasoline and kerosene. Sulphur is present in varying quantities in the low grade oils which in certain instances may necessitate special treatment.

Oils from the Gulf field (the Coastal Plain of Texas and Louisiana) are high in asphalt and low in gasoline. Much of the sulphur is present as sulphureted hydrogen which can be removed by steaming.

Oils from Wyoming and Colorado are mainly paraffin base, though there are some heavy asphaltic oils in Wyoming.

California oils are chiefly asphaltic with practically no paraffin and with more or less sulphur. The chief products are fuel oils, kerosenes, lubricants and oil asphalt, with a little gasoline from the lighter southern oils. The gravity ranges from 12° to 30° Bé. (See "Petroleum in 1915;" p. 573, U. S. Geol. Survey.)

Mexican oil, like the oils from the Gulf field, are of low gravity, 14° to 19° Bé., and they are high in sulphur compounds. The oil is largely used as fuel oil.

The oils may be arranged roughly in the order of their gravities, beginning with the lightest oil (highest Baumé gravity): Pennsylvania, Illinois, Caddo (Louisiana), Kansas and Oklahoma, and some oil from California. Very heavy oils come from the Gulf field (southern Texas and Louisiana), from Mexico and from most California fields.

Chemical Composition.—Petroleum or crude mineral oil is made up chiefly of a mixture of compounds known as hydrocarbons, having a composition of from 12 to 14 per cent. of hydrogen and 84 to 86 per cent. of carbon. These numerous hydrocarbons vary markedly in boiling point, from the light hydrocarbons like methane (CH_4) and ethane (C_2H_6), found in natural gas, to heavy solid bodies like paraffin, or asphalt and viscous oils which cannot be distilled without decomposition.

The hydrocarbons in petroleum belong to several different chemical series, depending on the amount of hydrogen present with the carbon or on the way the carbon is combined with itself. Pennsylvania petroleum is made up largely, but not entirely, of "paraffin" hydrocarbons which have the general formula C_nH_{2n+2}. The paraffin-base oils are more likely to yield important percentages of gasoline and kerosene on simple distillation, than the asphalt-base oils, as these light oils belong chemically to the "paraffins."

The hydrocarbons in the asphalt-base oils consist largely of unsaturated hydrocarbons or of hydrocarbons of the naphthene series (polymethylenes). These hydrocarbons have the general formulas C_nH_{2n} and C_nH_{2n-2}. Sometimes still less hydrogen is present as in some California oils which consist partly of aromatic compounds similar to those from coal tar with the general formula C_nH_{2n-6}. Besides having less hydrogen than is present in the "paraffins," the naphthenes (polymethylenes) are cyclic compounds while the paraffins are "chain" compounds. In these cyclic compounds, the carbon is united to form at least one ring, usually of the polymethylene type, such as,

$$\underbrace{CH_2.CH_2.CH_2.CH_2.CH_2}$$

while in the chain compounds, the carbon is united in an open chain, such as,

$$CH_3.CH_2.CH_2.CH_2.CH_3.$$

The above discussion does not cover the field by any means, as the subject is very complex, several series being present in most oils in varying proportions. Heavy oils, like the Texas oils, usually contain a large proportion of naphthenes. The fact that oils are different in composition from the Pennsylvania oils does not condemn them for any use, but necessitates finding out exactly what they are suitable for without forcing them to meet certain artificial requirements which were devised for use with other oils.

Heavy Pennsylvania lubricating oils consist largely of naphthenes or hydrocarbons of the C_nH_{2n} and the C_nH_{2n-2} series and not of paraffins as generally supposed. In other heavy oils the series C_nH_{2n-4} may also be present. The true unsaturated hydrocarbons of the olefine series are not present to any important extent in crude petroleum, but are present in ordinary cracked distillates. Aromatic hydrocarbons are present in limited amounts in most petroleums, and in considerable amounts in California petroleums.

Prof. Mabery, who has done valuable work on the composition of American petroleums, has shown that the paraffin hydrocar-

bons have a low lubricating value. He has also shown that the viscosity of hydrocarbons increases very rapidly with increase in molecular weight, so if high viscosity products are to be made, distillation must be conducted with as little decomposition as possible (*J. Am. Chem. Soc.*, pp. 992-1001, 1908).

The separation of the individual compounds from petroleum is practically impossible on account of the boiling points of the compounds being modified by presence of the other hydrocarbons in the mixture. Separation into groups of compounds with certain boiling limits is carried out on a large scale for the production of such commercial products as gasoline, kerosene and the various lubricating oils.

Hydrocarbons resist chemical action to a considerable degree, and so petroleum oils show little tendency to attack metals. Animal and vegetable oils show considerable tendency to form acid.

Origin of Petroleum.—Since different petroleums have very different compositions, there is naturally a great variety of theories to account for the origin of crude petroleum. Of the inorganic theories, which depend largely on the action of water on heated metallic carbides somewhat as acetylene is produced commercially, Clarke says (Data of Geo-Chemistry, p. 641, 1908) that "There is no evidence to show that any important oil field derived its hydrocarbons from inorganic sources."

The theories which accord with most of the facts are the theories of organic origin from the decomposition of animal and vegetable remains. Doubtless all types of organic matter have contributed their quota in varying amounts. Some oils, as in certain Texas fields, show evidence of marine animal origin. The considerable percentages of nitrogen compounds present in some oils strongly indicate animal origin.

The original differences in petroleums have been further modified by the migration of the oil, or its filtration through different strata which changes the composition of the oil.

Field Production, Storage and Transportation.—Oil is reached by bored wells varying in depth in different fields from 100 to over 4,000 ft. If the gas pressure is sufficient, a flowing well or

"gusher" may result, particularly when the well is first brought in. The maximum flow is usually immediately after oil is struck, some wells coming in with a flow of thousands of barrels per day, as the famous Beaumont well with 70,000 per day.

The oil is run into large metal or concrete storage tanks in the field, and is sent to the refineries by means of tank cars or pipe lines. Pipe lines run from the Oklahoma fields to the Atlantic Seaboard by way of Chicago. The Oklahoma fields are also tapped by pipe lines from the Gulf.

CHAPTER II.

THE REFINING OF PETROLEUM.

For the manufacture of lubricating oils and other valuable commercial products, crude petroleum is refined by distillation and by filtration or chemical treatment. Distillation separates the hydrocarbons into groups of different boiling points which find various commercial uses.

When petroleum is heated, it becomes more fluid by melting certain substances present in the petroleum, or by decreasing the cohesion between the liquid particles. If the temperature is sufficiently high, some of the crude petroleum will evaporate and can be condensed so as to yield gasoline, kerosene, and various distillates. During the process of heating, some of the hydrocarbons may be decomposed or "cracked" by the heating, yielding products of lower boiling point than those present in the original petroleum. Such decomposition is especially likely to occur if there is over-heating or prolonged heating, or if certain sulphur compounds are present. Distillation of even the lightest of the petroleum products cannot be effected without evidence of some decomposition. The heaviest part of the petroleum cannot be distilled without decomposition with the formation of free carbon or "coke."

In distilling lubricating oils, the best lubricants are obtained by processes which prevent prolonged heating or overheating of the oil, and which therefore cause the least amount of decomposition or "cracking" of the compounds originally present in the crude oil.

There are two processes in general use for the distillation of petroleum: Fire distillation and steam distillation. Steam distillation will be described first and in some detail as the best lubricants are made by it and as certain lubricants, such as steam-cylinder oils, can be made in no other way.

Steam Distillation.—The crude petroleum is put into large horizontal, cylindrical stills of 250 to 1,200 barrels capacity, made of sheet steel supported on brick-work. Heat is applied by means

of direct fire under the still, and as soon as the heating has begun steam is introduced by means of perforated pipes reaching nearly to the bottom of the oil in the still. The steam stirs the oil and so prevents local over-heating, and at the same time the escaping steam carries off the oil vapors as soon as formed so that they do not condense and drop back into the hot oil. The oil vapors go out through large pipes in the dome of the still and are condensed in a vertical tower condenser. In this condenser the heavy oils condense first near the bottom and the light oils condense last near the top. Thus with this type of condenser the oil may be separated into groups during the first distillation. With other types of condensers the distillates may have to be redistilled for this separation into groups.

The groups so collected are, in the order of their boiling points, (1) crude naphthas, (2) illuminating oils, (3) gas oil, (4) light lubricating distillate, (5) heavy lubricating distillate, and (6) undistilled residue. The distillation is usually stopped just above 600° F. The residue in the still is suitable for cylinder stock if Pennsylvania or other paraffin-base stock has been used. The various distillates are distilled to rid them of light and heavy ends and to render the removal of the paraffin from the lubricating distillates less difficult.

The use of steam causes the distillation to proceed at a temperature of at least 100° F. below what would be required without the use of steam. Since "cracking" is largely prevented, the yield of gasoline and kerosene is greatly reduced by the use of steam. Steam distillation is applied to paraffin-base oils mainly, but may be used with other oils as well. Paraffin-base petroleums may also be fire distilled instead of steam distilled in order to increase the yield of gasoline and kerosene.

The use of steam not only gives better grades of lubricants, but it increases the yield of lubricating oils as well, particularly of cylinder stock. A partial vacuum may be used along with the steam to aid further in the distillation for special products, as for the production of vaseline or special filtered cylinder stocks. Vacuum stills and continuous stills have not had a wide use in this country.

Instead of the "tower" condenser for separating into groups during the first distillation, the "cut" is often made for the different groups on the basis of the gravity of the distillate.

The groups obtained by steam distillation may be treated as follows:

Gasoline.—The crude naphthas are treated in turn with strong (66°) sulphuric acid, washed with water, then with caustic soda solution, and finally with water again. They are then distilled with steam to make the light and heavy gasolines or naphthas of commerce. The heavy ends are added to the crude kerosene distillate.

Kerosene.—The crude kerosene is steam distilled, the first part of the distillate being added to the crude naphtha distillate and the last part or "tailings" being added to the gas oil distillate. The main distillate is chemically treated (see gasoline) and is then filtered through fuller's earth to make the commercial grades of kerosene. Only "water white" kerosene is made by steam distillation, but the first part of the kerosene distillate from fire distillation of petroleum is also "water white" oil.

Some of the oils heavier than kerosene may be collected separately and made into special burning oils, such as mineral seal oil for railroad use.

Lubricating Oil Distillates.—These are distilled a second time from fire stills by the aid of steam, the undistillable residue going into fuel oil. The oils are chilled and filter-pressed to remove paraffin wax. They may be partly distilled again, or "reduced" to remove the light oils and so raise the viscosity and the fire test. The light oils distilled off in this reducing process may be run into the gas oil distillate or made into thin lubricating oils called non-viscous neutrals. The reduced lubricating oils are filtered through fuller's earth or bone-black to improve the color and remove impurities and are then ready for use as "viscous neutrals."

Cylinder Stock.—The residue in the still, if a paraffin-base crude has been used, is a steam refined cylinder stock. If the temperature has been carried well above 600° F. during the distillation

most of the paraffin has been distilled off. To make a filtered cylinder stock, the residue is "cut back" with crude naphtha, chilled and filter-pressed or otherwise filtered, and the gasoline finally recovered. The product is a filtered, low cold-test cylinder stock.

Fire or Destructive Distillation.—The more usual method of distillation has been to distil without the aid of steam, as this gives not only the gasoline and kerosene actually present in the crude oil, but additional light distillates formed by "cracking" much of the heavy hydrocarbons.

The cracking is accomplished by partly drawing the fire after the regular gasoline and "water white" kerosene distillates are off, so that the oil vapors are not removed from the still as soon as formed but condense on the upper part of the still and run back into the hot oil. The prolonged and excessive heating to which the oil is thus subjected breaks down the heavy hydrocarbons into lighter hydrocarbons which distil at a lower temperature, greatly increasing the yield of illuminating oil and somewhat increasing the gasoline output. The kerosene thus made has some color and a low flash point, and much of it goes into the export trade as low test oil or is used as "standard white" oil. Considerable unsaturated hydrocarbons, or olefines, are present from the cracking. These light distillates are chemically treated and redistilled with steam as stated above for steam distilled oils.

After the burning oils are all off, the "tar" residue, amounting to 10 or 15 per cent. of the original crude, is run into "tar-stills" of some 250 barrels capacity and is destructively distilled by fire until only dry coke remains in the still. The distillate is pressed to remove paraffin wax and the liquid portion is used as paraffin oils after chemical treatment and final steam fractionation.

The residue from the distillation is coke instead of cylinder stock.

Yields.—While the amount of the different products varies considerably with the crude used and with the details of the refining process, some idea can be gained from the following table

as to the relative proportion of commercial products in different cases:

Kind of crude Method of distillation	Penn. Steam and fire	Penn. Fire	Okla. Fire
	Per cent.	Per cent.	Per cent.
Gasoline and naphthas	15–20	20–25	25
Kerosenes	30–45	60–75	25–30
Gas oil and fuel oil	15–20	....	25
Paraffin wax	2	1–2	1
Lubricating oils (dist.)	10–15	5	10
Cylinder stock	15	●	●
Coke	0	4	4

Western Lubricating Oils.—The so-called western oils are made from crudes which contain little paraffin. The procedure is similar to the refining of Pennsylvania oils, except as the procedure may be modified by the character of the merchantable products possible. Most of the California crudes, and much of the Oklahoma and Texas crudes are "topped" for the removal of gasoline and illuminating oils, and the undistilled residue is sold directly as fuel oil without further refining. Very little lubricating oil is produced west of the Mississippi River.

Oklahoma crude, and some heavy crudes from Texas and California, are now worked up for the manufacture of certain lubricants, such as cylinder oil, red engine oil and lighter lubricating distillates. The distillates have higher gravities, lower flash points, higher viscosities at low temperatures (70° or 100° F.), and lower cold tests, than do Pennsylvania products of the same class.

The residue from asphalt-base oil is asphalt instead of cylinder stock, but mixed base oil may yield some cylinder stock by proper treatment.

On account of the high Baumé gravity of Oklahoma crude and the large percentage of gasoline and kerosene, the value of some Oklahoma oils ranks close to Pennsylvania crudes.

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CHAPTER III.

THE REFINED PRODUCTS.

A. LIGHT DISTILLED OILS.

Gasoline or Naphtha.—The light naphtha of 88° Bé. is known as petroleum ether. It distils at a lower temperature than does gasoline.

Gasoline, motor fuel, or heavy naphtha has a gravity between 56° Bé. and 70° Bé. It is obtained by the simple distillation of petroleum, or by "cracking" petroleum oils by some of the recent processes for producing "synthetic" gasoline. It is also produced by blending certain gases from natural gas with heavy gasoline to make the so-called casing-head gasoline. Commercial gasoline may contain products ranging from 40° to 90° Bé. While a large amount of very volatile constituents facilitates explosion in the motor, the extremely volatile products increase the hazard in using and in shipping, and so the Bureau of Explosives specifies maximum pressure limits for gasoline shipped by common carriers.

Kerosene.—The gravity of kerosene ranges from 40° to 48° Bé., the distillation range being from 150° to 300° C. (302° to 572° F.). For Pennsylvania water white oil the gravity is usually above 46° Bé. and a slightly higher boiling point limit can be used, but with the removal of more of the lighter oils for incorporation into gasoline, some of the heavier oils above 275° C. must also be left out in order to give a product of good candlepower.

Several grades of kerosene are generally recognized: Water white oil made by straight distillation of the crude, and prime white oil made by cracking the crude during distillation. The former commands the higher price and is considered the more satisfactory product. Much of the latter goes into the export trade as low flash oil. The flash point of kerosene is adjusted largely to meet State requirements. Water white kerosene is usually 150° fire test.

Mineral Sperm Oil or Mineral Seal Oil.—These heavy illuminating oils, of 300° F. fire test, distil off after the kerosene. They are used for railroad and similar illumination where steady burning and only small illuminating power are necessary. The gravity ranges from 34° Bé. to 42° Bé.

Gas Oil.—The oils distilled between the illuminating oils and the light lubricating oils are used for carbureting water gas and other gas to improve the illuminating power. This gas oil is a cheap product. In re-distilling the lubricating oil distillates, the light ends are run into the gas oil. This product is sometimes used for fuel oil.

B. DISTILLED LUBRICATING OILS.

Paraffin Oils.—These oils are manufactured by fire distillation (without steam) and are decolorized or bleached by treatment with sulphuric acid. The final colors are yellow or red. Some of the better grade products are filtered instead of acid treated. The gravity seldom goes above 30° Bé. even for the thinnest oils, and the viscosity is low as compared to the gravity as the method of distillation tends to break down the more viscous portion of the oil. The viscosity ranges from that of heavy kerosene to 300 Saybolt at 100° F. The light oils can be used for spindle oils in the place of the usual non-viscous neutrals. The heavy oils are used for engine oils, loom oils, motor oils, etc. These oils are not so expensive as are neutral oils. The high viscosity paraffin oils are made by "reducing," that is, by distilling off the lighter oils by means of steam and fire.

Neutral Oils.—These oils are manufactured by steam distillation, and are of high viscosity in proportion to their gravity. After the wax has been removed from the mixed lubricating oil distillate, the oil is "reduced" by steam distillation to remove the lighter oils. These light oils constitute the "non-viscous" neutrals, while the residue from this final distillation constitutes the "viscous" neutrals.

The non-viscous neutrals usually have a gravity well above 30° Bé. and a low viscosity, suitable for light spindles. These oils are considered the best spindle oils as they do not stain like

paraffin oils if properly filtered. These oils are not usually acid treated. The viscosity is 45 to 65 at 100° F.

The viscous neutrals are usually slightly above 30° Bé. and have viscosities ranging from 80 to 200 at 100° F. These oils are suitable for motor oils, turbine oils, gas engine oils, air compressor oils, and for the highest grade service. The color is reduced by repeated filtration through fuller's earth instead of by acid treatment. In order to make the heavier oils, the viscous neutrals are blended with small amounts of high-flash, filtered steam-cylinder stock. Blended oils of high viscosity may have gravities as low as 27° Bé., even when from Pennsylvania stock. Viscous neutrals are also made from other stocks than Pennsylvania stocks, in which case the gravities will be much lower and the viscosities much higher than can be obtained from Pennsylvania distillates alone.

Spindle Oils.—These are low-viscosity oils, of 45 to 100 Saybolt at 100° F. They may be light paraffin oils, but are usually and preferably the non-viscous neutrals.

Loom Oils.—Neutral oils are used, but the use of paraffin oils, similar to light engine oils, is common practice. The oils have been acid treated in most instances.

Engine Oils.—Commercial engine oils are usually the heavier paraffin oils. The heavier oils are nearly always red, but the amount of color depends on the amount of acid treatment or of filtration. The color is not an index to the lubricating quality. The heavier engine oils may be built up by the addition of cylinder stocks to heavy distillates. Viscous neutrals were formerly much sold as engine oils, but high-gravity neutrals now go largely into the motor oil trade. Low-gravity western neutrals are still sold as engine oils. For circulating oil systems, neutral oils are more satisfactory than paraffin oils as they separate from water better.

Motor Oils.—For lubricating gasoline engines of all kinds, the viscous neutrals are considered most suitable. While Pennsylvania products are generally given preference, oils can be made by the same process from other crudes with equal success. For

western oils, the gravity is lower and the viscosity may be higher. The heavy motor oils are made by the addition of special steam-cylinder stocks to viscous neutral oils. Paraffin oils make less desirable motor oils.

Turbine Oils.—These are similar to the lighter motor oils. The neutral oils separate from water better than do the paraffin oils and so are more desirable in actual service.

Air Compressor Oils.—These are similar to the lighter motor oils.

Paraffin.—Solid paraffin, though not used as a lubricant, comes over with the lubricating oil distillates and has to be removed by chilling the oil and filter pressing. Ordinarily the oil distillates have to be vaporized twice in order to get the paraffin in condition to filter from the oil. The crude "scale wax" is further treated to make the paraffin of commerce, the treatment consisting of "sweating" to remove oil and filtering to remove tar and asphalt.

C. UNDISTILLED OILS.

Cylinder Stocks (Steam Refined).—By steam distillation of Pennsylvania oils and other paraffin-base oils, a heavy undistilled oily residue is left in the still. This can be used as a cylinder stock after removing some of the solid impurities. Steam refined stocks of high fire test (over 600° F.) are not filtered as filtration is difficult and the high temperature has removed most of the paraffin. The flash test ranges from about 550° to 600° F. and the fire test from 600° to 700° F. Low fire test stocks are more likely to contain paraffin and high test stocks to contain tarry matter. Cylinder stocks should be free from tar, so the color should be green or brown and not black.

The viscosity of Pennsylvania stocks runs from 140 to 280 at 210° F. for the steam refined stocks. The highest viscosity Pennsylvania stocks do not run below 24° Bé. in gravity.

Cylinder Stocks (Filtered).—Steam refined stocks can be cut back with crude gasoline and filtered through fuller's earth or boneblack to remove carbon and coloring matter. The highest

fire test stocks are never filtered, the fire test of filtered stocks rarely being over 600° F. Also stocks of over 160 viscosity are rarely filtered. Pennsylvania stocks do not run less than 26° Bé. Filtering reduces the viscosity of cylinder stocks.

Bright stocks are generally low cold test stocks made in the preparation of petrolatum.

Cylinder Oils.—See Compounded Oils below.

Petrolatum (Vaseline).—Special Pennsylvania oils are carefully distilled, with steam and vacuum, until the solid uncrystallizable paraffins are reached. The product is then filtered through boneblack after cutting back with gasoline. The light colored residue, after driving off the gasoline, is a pasty mass called vaseline. The darker colored oils which filter later are used as cylinder stock.

Car Oils (Black Oil, Reduced Oil, Well Oil).—The residue left after distilling off the lighter lubricating oils by fire distillation is a black oil which is sold in the unrefined condition as car oil. For winter car oil, the distillation can be stopped earlier, or the residue can be cut back with some light distillate.

Fuel Oils.—Many of the western crudes, as from California, are sold for fuel, either as they come from the wells, or after "topping" or "stripping" to remove the light oils. Also light and heavy ends from redistilling lubricating oils are run into the fuel oil. Distilled fuel oils are really heavy gas oils.

D. MIXED OILS.

Blended Oils.—Blended oils are made by mixing mineral oils, either distillates or cylinder stocks. Sometimes oils are "cut back" by addition of a small amount of low viscosity oil to reduce the viscosity of an oil. An example would be the addition of a distillate to a cylinder stock to lower its viscosity or the addition of a distillate to car oil to change a "summer" car oil to a "winter" car oil. Sometimes the viscosity of light oils is "built up" by the addition of heavy oils, as in adding cylinder stocks to engine oil distillates to make heavy motor oils.

In mixing or blending oils it is well to remember that the vis-

cosity of the mixture is always decidedly lower than would be calculated from the viscosities of the two oils and the proportions taken. Where the oils are very different in viscosity the variation from the expected viscosity is greatest. The viscosity of the mixture may be as much as 30 per cent. below the expected viscosity, but it is usually from 5 to 15 per cent. lower than the calculated viscosity.

The gravities are as would be expected, but the flash point is lower than the mean of the mixture. (See Sherman, T. T. Gray and Hammerschlag on "A Comparison of the Calculated and Determined Viscosity Numbers [Engler] and Flashing and Burning Points in Oil Mixtures," *J. Ind. & Eng. Chem.*, pp. 13-17, 1909; also T. T. Gray on "A Comparison of the Engler and Saybolt Viscosities of Mixed Oils," 8th Int. Cong. Appl. Chem, X, pp. 153-158, 1913).

Compounded Oils.—Compounded oils are made by mixing or blending a mineral oil with a fatty oil. The chief compounded oils are cylinder oils, made by dissolving animal oil or other fatty oil in cylinder stocks, and marine engine oils, made by dissolving rape oil or blown rape oil in mineral oil. Compounded oils for other purposes are now seldom used.

The viscosity of a compounded oil is much less than the theoretical viscosity calculated from the oils used in compounding.

E. MISCELLANEOUS OILS.

Rosin Oils.—These are the heavy oils from the distillation of rosin. They are used for grease making, for transformer oils, in printing inks, in paints, and in the purified condition as lubricating oils. After the rosin acids have been largely removed, the rosin oils are chiefly special hydrocarbons.

Coal Tar Oils.—These belong to the aromatic series of hydrocarbons (C_nH_{2n-6}) which are cyclic compounds. They are sometimes used in lubricating greases. The heavier tars may be used in special thick greases for chains, etc.

Thickened Oils.—Oils may be thickened by the addition of certain soaps to form greases, or with certain aluminum soaps to

form mineral castor oils. Caoutchouc is also added to oils to increase their apparent viscosity.

Shale Oil.—Shale oil, from the destructive distillation of oil-shales, has been produced to an important extent in Scotland and elsewhere. The large quantities of oil-shales in Colorado and other states may be similarly developed for lighting, power and lubricating purposes.

F. SPECIAL PROPERTIES OF MINERAL OILS.

The advantages of petroleum lubricating oils over animal and vegetable oils are the lower cost of the mineral oils, the non-oxidizing and non-gumming character of mineral oils and their general stability, and the great range of viscosity obtainable. This wide range in viscosity of the products available makes a knowledge of the viscosity of the various mineral oils not only desirable but necessary to meet different lubricating conditions. The chief disadvantage of mineral oils consists in the non-adherence of the oils in presence of hot water, and in the rapid decrease in viscosity under heat. Animal and vegetable oils also lose viscosity rapidly under heat. By proper attention to the temperature at which an oil is to be used, a mineral oil can be obtained which will meet all viscosity requirements at the desired temperature.

Coefficient of Expansion.—Oils expand rapidly with rise of temperature and so decrease in specific gravity, the amount of expansion for oils of the same specific gravity being the same. The expansion for gasolines is from 0.0006 to 0.0007 for each degree F.; for kerosenes 0.0005; for spindle oils 0.00045; and for lubricating oils of 0.890 to 0.950 specific gravity (17° to 27° Bé.) 0.0004. In filling cars and barrels sufficient space must be allowed for expansion (see Bureau of Standards Circ. No. 57).

Specific Heat of Oils.—This is important in oil refining or wherever oils have to be heated. It is of special importance in relation to the cooling action of oil on bearings. Oils do not vary

greatly in this particular, the specific heat usually being between 0.45 and 0.50 as compared to water at 1.

Heat of Combustion.—The heat of combustion varies from about 16,000 to 22,000 B. t. u., the average being about 19,000. The heat of combustion is higher for the light oils. (See under specifications, etc., for Gasoline and Fuel Oils pages 204, 210 and 211.)

CHAPTER IV.

FRICTION AND LUBRICATION.

A large percentage of the power applied to all kinds of machines and manufacturing plants is used in overcoming friction. This power, which is largely lost or wasted so far as doing useful work is concerned, generally amounts to from 20 per cent. to 80 per cent. or more of the total power developed.

Unnecessary Stresses.—Important sources of power losses are improperly aligned shafting or bearings, and tight belts, which cause excessive pressures and stresses which can only be reduced by mechanical adjustment. Properly aligned machinery, bearings that do not bind, and large pulleys with loose belts will greatly reduce power waste and depreciation of machinery. The first step in the reduction of friction is to remove unnecessary stresses by the best possible adjustment of the moving parts.

Two Kinds of Friction.—In the operation of most machinery two kinds of friction have to be overcome by the expenditure of power: Solid friction which results from actual contact of the moving surfaces, and fluid friction which is due to the resistance the lubricant offers to motion. Since solid friction is much greater than fluid friction, lubricants are used to separate the moving parts of machines, and so substitute fluid friction for solid friction. With smooth bearings at high speeds and under moderate pressures, this substitution is practically complete with a suitable oil, and the friction developed is proportional to the true viscosity of the oil.

Solid Friction.—More or less solid friction results where the lubrication is deficient either in quality or quantity. On account of the minute irregularities of bearings and journals, and on account of the tendency of metals to weld or "sieze" under the influence of pressure, the resistance to motion is high where the metals are in actual contact. Excessive initial power is required in starting a machine as much of the oil has been squeezed from between the bearings so that the surface depressions and pro-

jections interlace somewhat like cogs. After the machine is in motion, if the lubricating film is not sufficiently thick, or if the bearing is not smooth, the solid projections still strike or press against each other and consequently varying degrees of solid friction result.

The effects of solid friction are relatively large power losses, heating of the bearing, lowering of the viscosity of the oil by heating, and wear. As the bearings may be continually roughened by the sliding contact, the conditions become ideal for increased frictional losses. In extreme cases, serious seizing of the bearing and journal may occur so that proper lubrication becomes impossible and the removal of the bearing becomes necessary. In most cases, the effect will be continued wear and continuous waste of power through excessive solid friction. With good lubrication, serious abrasion is entirely absent, and wear and solid friction are reduced to a minimum.

Solid and Fluid Friction.—While for heavy, slow-moving machines solid friction is generally an important factor in power consumption, in the usual bearings and journals at normal speeds and pressures, relatively more power is used in overcoming resistance due to the oil. This is contrary to the popular belief which ascribes most of the power losses to wear resulting from actual contact of the bearing and journal. If the lubricant does not keep the bearing and journal apart almost entirely during normal running, there is something wrong with the lubricant or with the bearing.

Fluid Friction.—In perfect lubrication, the moving part is entirely supported or "floated" on a film of oil which is of sufficient thickness to keep the journal and bearing apart under all reasonable conditions. To maintain such a film, the oil must have sufficient viscosity or "body." Pressure, speed, working temperature, condition of the bearings and method of oil feed determine the most advantageous oil to use, the effect of these different factors being as follows:

(1) With other conditions the same, high pressures require

oils of higher viscosities than do low pressures, as high pressures tend to squeeze the oil from between the friction surfaces.

(2) With the same pressures, a fast moving journal can be satisfactorily lubricated with a thinner or less viscous oil than can a slower journal. This is because the speedier journal sucks or pulls in more oil between the moving parts and so aids in maintaining the film.

(3) For bearings that operate at high temperatures, as on electric motors, an oil of greater viscosity is required than for lower working temperatures under similar speeds and pressures. Raising the temperature greatly reduces the viscosity of an oil.

(4) For rough bearings, an oil of high viscosity is required in order to maintain a thick film which will reduce actual contact of the bearing and journal to a minimum.

(5) With a circulating oil feed, or force feed, oil of lower viscosity can be used on account of the increased amount of oil reaching the bearing which partly compensates for the oil squeezed out. The excess of oil also tends to reduce the temperature of the oil film and cool the bearing so that the working temperature is lower and the working viscosity is higher than where less oil is fed.

In general, for low pressures and high speeds a thin oil is desirable; for high pressures and low speeds, a thicker, more viscous oil is necessary. Pressure per square inch is meant and not the total pressure on the bearing, while speed refers to the friction speed of the contact surfaces and not to the actual rate of rotation. For rubbing speeds of less than 100 feet per minute, the oil film does not form properly for satisfactory oil lubrication.

With good lubrication, or practically perfect lubrication, the friction is chiefly fluid friction, and the main factor in determining the amount of friction is the viscosity of the oil, so far as lubrication is concerned. Obviously then, an oil which has just sufficient viscosity to carry the load under all reasonable conditions, but no greater viscosity, is the ideal lubricant.

Viscosity.—By the viscosity of an oil is meant its internal friction or its resistance to flow. It refers to the same property as

do the terms body and cohesion. For true liquids viscosity varies inversely as fluidity.

Viscosity is usually measured by noting the time required for a given volume of an oil to flow through a definite sized opening or tube under a definite pressure. With commercial viscosimeters, such as the Saybolt and the Engler, the tube is too wide and too short for the real friction of the oil to be accurately registered, consequently such instruments do not show the true viscosities of oils, though such instruments serve to classify oils in the order of their viscosities. For high viscosity oils, above 300 Saybolt, the true viscosities are practically proportional to the Saybolt viscosities, but for low viscosity oils the viscosities observed are not relatively proportional. Thus an oil of 50 Saybolt viscosity has considerably less than one-fourth of the absolute (true) viscosity of an oil which reads 200 Saybolt. Also, the difference between two low viscosity oils, for instance of 50 and 60 Saybolt, is much greater than the two figures would indicate.

Friction and Viscosity.—It is generally accepted that under good lubrication conditions, the frictional resistance necessarily varies with the pressure, with the velocity of the friction parts, and with the viscosity of the oil at the working temperature. It is, however, not so generally accepted that under definite conditions of speed and pressure, the coefficient of friction is solely dependent on the viscosity of the oil. This is Ubbelohde's theory which he has substantiated by calculating the actual coefficient of friction for many oils, including American oils, from the true viscosities of the oils (*Pet. Rev.*, 27, pp. 203 and 325-326; *Petroleum*, 7, pp. 773-779, and 882-889; cf. *Chem. Abs.*, pp. 1986, 2521, and 2839, 1912; and pp. 248 and 2678, 1913). Ubbelohde states that the reason this relation has not been generally recognized before is due to the fact that commercial viscosimeters do not give the true viscosity, or readings relatively proportional to the true viscosities. It has been the practice also to make viscosity readings at temperatures which did not accord with working conditions and so the relation was further obscured.

The value of oils as lubricants has been explained by many

observers on the basis of such properties as "oiliness," unctuosity, etc., alleged to be independent of viscosity, which were considered to have an important influence in forming and maintaining the film. While these explanations have not been absolutely disproved, there has never been any tangible evidence on which to base any solid argument in favor of their validity. Factors which are important are adhesion (outer friction) and capillarity, but according to Ubbelohde all oils possess sufficient adhesiveness as all oils cling to or "wet" all solid bodies.

In connection with this contention that adhesion is always adequate, and that there is no "slip" of the oil where it is in contact with the metal, and that the outer friction of the oil on metal is practically infinitely great and independent of the wetting or adhesion, it is of interest to note the statement of Prof. Gill (Rogers and Aubert's Industrial Chemistry, 1st Ed., p. 563) that in performing friction tests with a friction machine the effects of the oil previously used on the machine persist for about eight hours. This indicates that the oil in actual contact with the metal is difficult to dislodge even when the "pores" of the metal surface are at a minimum.

Ubbelohde's experiments prove that oils of the same viscosity, whether refined oils or unrefined oils, distilled oils or undistilled oils, have the same coefficient of friction, without regard to the origin of the oil.

Viscosity and Temperature.—As the temperature rises, viscosity decreases rapidly. This makes it especially important that the viscosity be taken at the working temperature, or sufficiently near the working temperature to make possible an adequate comparison of the working viscosities of the oils used. The viscosity of most oil distillates is now taken at 100° F. and this is usually sufficiently high for all such oils, except possibly for heavy engine oils. Western oils lose viscosity faster below 100° F. than do Pennsylvania oils, but at temperatures above 100° F. the drop in viscosity is not much greater for western distillates than for Pennsylvania distillates.

When power acts to overcome friction, heat is generated as

will be noted from the rise of temperature of any bearing when the journal is in motion. The highest temperature observed in a bearing is necessarily much less than the temperature of the oil film actually supporting the load, and the true working temperature of the oil film is higher than generally supposed, with a correspondingly decreased viscosity for the oil.

In practice, high temperatures from friction accompany great power losses either by solid or fluid friction. Low temperatures above surrounding temperatures indicate small power losses.

Rise of temperature, even of a few degrees, greatly lowers the observed viscosity and the lowering of the true viscosity is even greater than indicated by the reading, on account of the defects previously noted in commercial viscosimeters.

Fatty oils (animal and vegetable oils) retain their viscosity somewhat better under heat than do mineral oils. This is especially true of sperm oil, although the viscosity of sperm oil is relatively low. Castor oil and blown oils are the only fatty oils having high viscosities at elevated temperatures.

One of the functions of a lubricant is to cool the bearing by absorbing and carrying off the heat from the friction surfaces. Lubricating oils vary very little in their heat absorbing capacity, consequently where considerable heat is developed, as in bearings around a steam engine, the temperature can be best kept down by a force-feed or by a circulating oil feed which feeds more oil to the bearing.

While the working viscosity of an oil is primarily the viscosity corresponding to the actual temperature of the supporting film, the viscosity of the oil at the other temperatures of use, such as the temperature at which steam cylinder oils are handled and fed, may be important and should receive proper consideration.

For a further discussion of viscosity and its determination see Index.

Oil Lubrication.—The above statements in regard to the relation of friction and viscosity apply primarily to oil lubrication. Successful oil lubrication is based on two fundamental principles:

(1) The use of an oil of sufficient viscosity to maintain a film

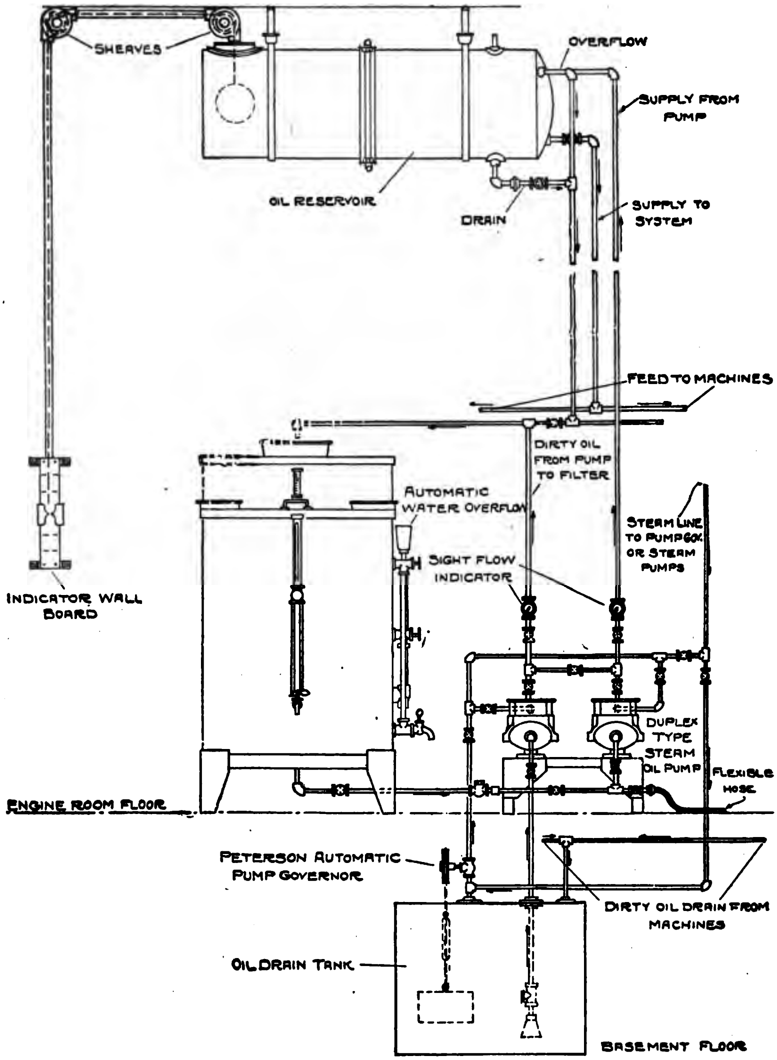
of adequate thickness under normal working conditions plus sufficient additional viscosity to prevent the bearings coming in contact during abnormal conditions. Since solid friction is so much greater than fluid friction, if the bearings come together appreciably, power will be used up and more or less wear result. A lubricant which does not keep solid friction and wear to a minimum does not meet the primary requirements of a lubricant.

(2) The use of an oil of only sufficient viscosity to meet the above conditions, as all additional viscosity results in the useless consumption of power. At high speeds, not only can an oil of lower viscosity be used, but any additional viscosity results in much greater power losses than would result at lower speeds. Fluid friction is roughly proportional to the square root of the velocity of the friction surfaces.

Imperfect lubrication with solid friction results where friction speeds are too low, or too little oil is fed, or the load is too great for the viscosity of the oil under the working conditions. Consequently for heavy shafting where the friction speeds are low, and in similar circumstances with other machinery, an oil of sufficiently high viscosity should be used. If the speed is low a reasonable excess of viscosity will result in little lost power.

Purity of Oils.—Numerous other tests are applied to oils besides the viscosity test. These are necessary to insure an oil that will be safe to use, or that can be used without undue loss from evaporation or decomposition, or without developing materials which would interfere with the oil feed or change the viscosity. Refining tests are applied to protect the bearings from the presence or the formation of injurious or gumming materials. These tests ordinarily have no direct bearing on the value of the oil so far as reducing friction is concerned, but are tests of the stability and suitability of the oil for the special conditions under which it is to be used.

Oil Testing Machines.—Tests made on the usual testing machines are generally unsatisfactory as the machines do not duplicate working conditions. Satisfactory results can be had by selecting an oil from the physical tests, especially the viscosity



Typical Central Oiling and Filtering System with Filter on Engine Room Floor and Receiver and Automatic Pump Governor in Basement.

(By courtesy of The Richardson-Phenix Co., Milwaukee.)

tests at the working temperatures, and checking the selection of the oil in service or on a service bearing.

Important contributions have been made by Prof. R. H. Thurston to the science of lubrication through his development and use of testing machines. Much of his work is given in his "Friction and Lost Work in Machinery and Mill Work," published in 1879, which is still the standard treatise on this subject.

Circulating Oil Systems.—With the development of complex, heavy machinery, automatic oiling devices have come into use which feed the oil where needed without continued attention. Circulating oil systems, operated by motors or by steam pressure, feed oil to the many friction points of Corliss engines, turbines, and dynamos, collect the excess oil as it flows from the bearings, separate entrained water by appropriate means, filter off dirt and precipitated matter, and continue the oil in service with little loss. Such oil may circulate through the system 500 times or more and still be in good usable condition, as a good oil does not wear out, though it naturally darkens in service even with proper filtration. A poor oil may develop acid under exposure to heat and air, or may emulsify with water and increase in viscosity.

In circulating systems, and with ring oilers and other devices for flooding bearings with excess oil, an oil of lower viscosity can be used than where just sufficient oil is fed, as the surplus oil serves to cool the bearing.

The importance of ample lubrication, such as afforded by flooded bearings and by bath lubrication, can hardly be stressed too much on account of the great reduction in friction losses through the free use of an oil of the right viscosity.

In connection with forced-feed lubrication, the following quotations from Technological Paper No. 86 of the Bureau of Standards, by W. H. Herschel, are of interest:

"Lubricating oils are used to reduce friction, and their effectiveness depends upon the manner in which they are applied as well as upon their quality. To obtain the best results there must be an abundant supply of the lubricant. It has thus become recognized as good practice, especially for high speed machinery, to use a forced-feed lubricating system, the oil

being pumped from a settling tank through the bearings and allowed to flow back to the tank. A filter is included in the circuit.

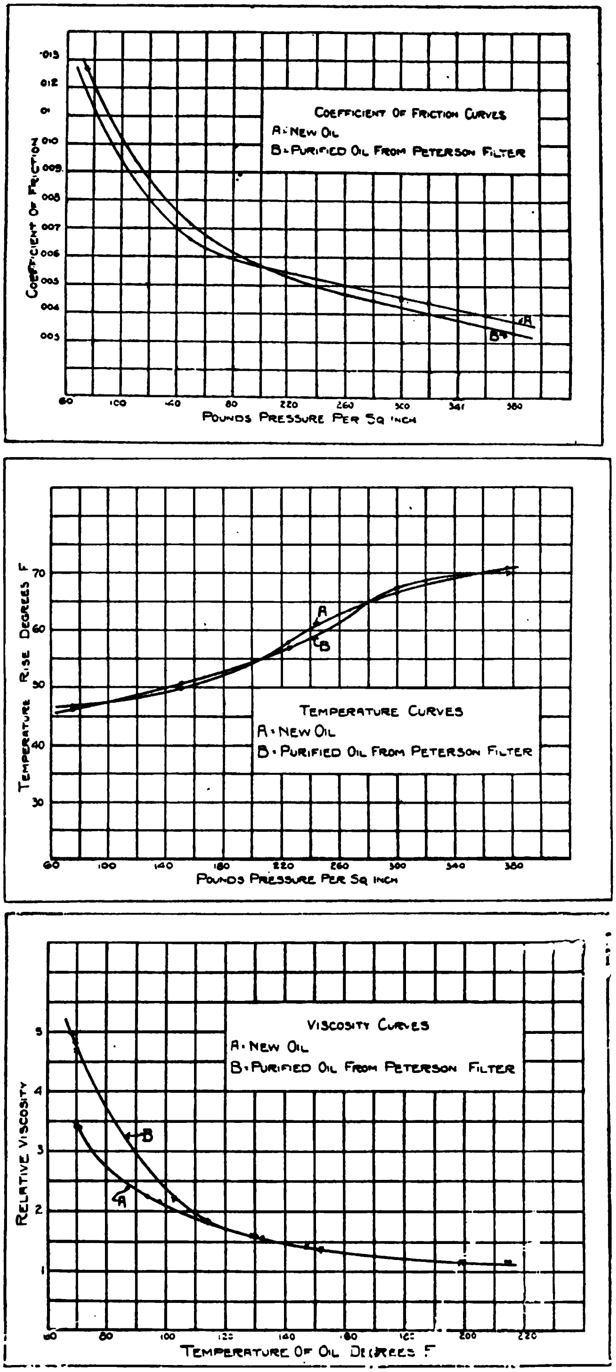
"It has been found that oils do not wear out mechanically and may be used over and over again. Thurston says, 'A mineral oil is usually just as good after use as before, apart from the impurities, which are removed by filtering.' Similarly Sabatié and Pellet conclude, 'The apparent result of all these different tests is that a used oil, received in good condition and *filtered with care* to rid it of the material which it may contain in suspension, preserves its different properties almost intact."

"It is on account of the necessity for filtering, upon which emphasis has been laid, that an emulsifying oil cannot be used in a circulatory system. An emulsion may clog the filter and result in damage to the bearings, due to the failure of the oil supply."

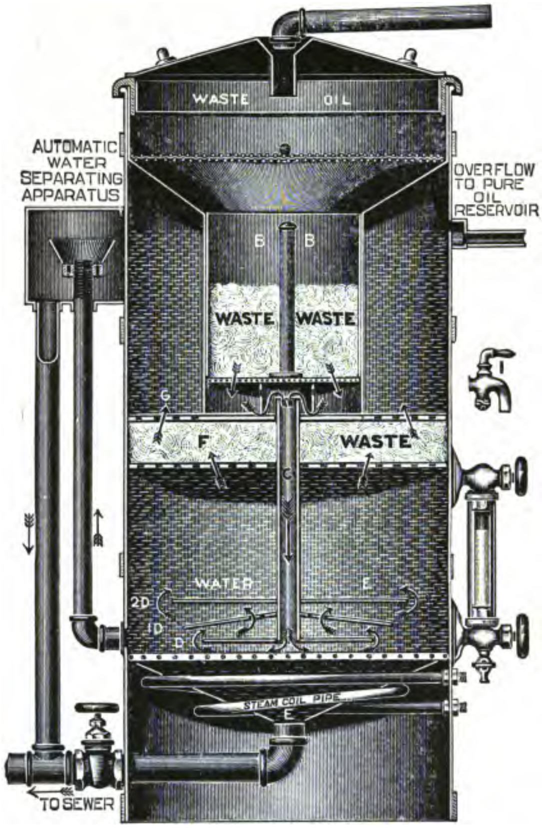
(See also Emulsification Test, pages 117-121.)

The accompanying curves show tests made on oil after use in a circulating system for one and one-half years of continuous day-and-night operation. The circulation was at the rate of 150 gallons per hour, or 1,800 barrels per month, three barrels of new oil being added to the system per month. The oil was used to lubricate 134 points on several engines and compressors. The upper curve shows the coefficient of friction on a Thurston Railroad Lubricant Tester at 360 revolutions per minute for new oil and for filtered oil. The middle curve shows the temperature of the bearings in this test with the two oils. The bottom curve shows the viscosities of the new and the filtered oil at various temperatures with an Olsen viscosimeter. The oil increased in gravity from 0.895 to 0.903 during the period of use. The increase in gravity is without special significance.

Bearings.—The design and fit of bearings greatly influence the quality of the lubrication. Bearings should be so constructed, by proper grooving or otherwise, and by proper location of the oil feed, that ample oil is drawn in or sucked in by the moving journal. In order to secure the best possible conditions for lubrication, the bearing should be smoothe and of softer metal than the journal. While an excessively soft bearing would not offer sufficient resistance to the load, a soft bearing soon beds or flows to fit the journal so as to support the load at all points.



Curves Showing the Relation Between New and Filtered Oil.
(By courtesy of The Richardson-Phenix Co., Milwaukee).



The Cross Oil Filter "Style B."
(By courtesy of Burt Mfg. Co., Akron, O.)

The area of bearings is designed to secure proper load per unit area. The area of the bearing should be just sufficient to maintain the load successfully under all conditions with the grade of oil to be used, as any excess area will increase the friction loss unless a thinner oil is substituted. For high speeds, the friction is practically independent of the load and is proportional to the area of the friction surfaces.

The proper fit of bearing for the lowest coefficient of friction is obtained by having the radius of the journal slightly less than

the radius of the bearing to give space for the oil film which is usually 0.0002 to 0.003 inch thick.

Ball bearings and roller bearings are generally lubricated with oil and thin grease, respectively, and offer less frictional resistance than do other bearings.

Grease Lubrication.—Good lubrication with oils is difficult to attain with slow moving machines under high pressures on account of the tendency of the lubricant to squeeze from between the friction surfaces faster than it is fed in by the motion of the journal. Since greases do not squeeze from bearings readily, but maintain a relatively thick film under pressure even when the journal is still, they are especially suited for slow or intermittent work where the loads are heavy. Sometimes oils of high viscosity can be used successfully for such work. For use on gears, greases are especially adapted as the unit pressures are high and the rubbing speeds slow.

Greases are not suitable for high friction speeds on account of their greater frictional resistance as compared to oils, though they do not offer excessive resistance to flow at low speeds. The coefficient of friction is higher for greases than for oils, which is another way of saying that greases offer more resistance to motion than oils do. Thin greases and greases of low melting point do not offer as great frictional resistance as stiff greases of high melting point.

Greases are also often used instead of oils for lubricating inaccessible parts of machines, for general convenience in application, for reducing the consumption of lubricant, to prevent splashing and to secure automatic feed.

Graphite as a Lubricant.—Flake and amorphous graphite have been widely used in conjunction with oils and greases for lubrication. The function of the graphite seems to be to build up the depressions in the friction parts and so make a smoother bearing. The effect is to reduce the friction, to make possible the use of a much thinner oil and to reduce the consumption of lubricant. For very heavy work and slow speeds, graphite is extremely valuable

in preventing abrasion and seizing, and for reducing solid friction, as in steam valves and cylinders.

Graphite also seems to form a veneer or coating which carries heavy loads without offering much resistance to motion. Only very finely divided graphite should be used, especially with bearings having small clearance. Very small amounts of graphite give the best results.

Considerable work has been done by Prof. Mabery on the effect of graphite on the coefficient of friction of lubricants, using oils mixed with 0.35 per cent. of deflocculated (Acheson) graphite, with favorable results (*J. Ind. & Eng. Chem.*, pp. 115-123, 1910, and pp. 717-723, 1913; also *J. Frank. Inst.*, Vol. 169, pp. 317-328). Other authorities also report decreased frictional resistance where graphite is added to oils.

Mica as a Lubricant.—In general, the action of mica in a suitable state of fineness is similar to the action of graphite in being a surface evener. Mica has been used largely in certain greases.

CHAPTER V.

LUBRICATION OF INTERNAL COMBUSTION ENGINES.

Most explosive engines using liquid fuel work on the four cycle principle. The oil reaches the cylinder wall either by being splashed or sprayed on the wall below the piston. In some cases the oil is supplied by a force feed, but usually the oil is largely splashed by the moving parts in the crank-case. The oil gets into the cylinder above the piston either by being rubbed up by the piston, or by being sucked in past the piston rings during the stroke preceding the compression stroke, that is, during the inlet stroke. In the stroke succeeding the explosion or firing stroke the lubrication must be effected solely by the small amount of unburned oil remaining on the cylinder walls and by the oil actually left on the piston rings.

In order to secure proper lubrication an oil must be used which resists decomposition at a high heat, which leaves little undesirable residue when exposed to heat or when burned, and which has sufficiently high viscosity to lubricate but not sufficient viscosity to prevent the rapid formation of an oil film or seal. While at the high temperatures which the oil attains the viscosity is very greatly reduced, yet the very high speed of the piston and the relatively small pressure exerted by a vertical piston against the cylinder wall makes an oil of very high working viscosity unnecessary.

Excessive viscosity will prevent the oil film from forming rapidly after the firing stroke. However, owing to the fact that the oil is used to seal the gap between the cylinder wall and the moving piston or piston rings, as well as for actual lubrication, an oil of a little too high viscosity gives better results than an oil of too low viscosity. A low viscosity oil, especially with loose piston rings, does not seal the cylinder properly and so results in hot gases leaking past the piston rings and contaminating the oil in the reservoir or sump, exposing the oil, which is repeatedly splashed on the cylinder wall below the piston, to fairly high temperatures for long periods. Also the use of an oil of low vis-

cosity may make necessary the use of excessive amounts of oil with the possibility of increased carbon formation in the cylinder.

So far as temperature conditions are concerned, the oil has two kinds of temperature to withstand: the temperature just below the flash point of the oil (200° to 400° F.) repeatedly for long periods of time as the oil is splashed on the cylinder walls below the piston and runs back into the oil reservoir, and temperatures of 200° to 800° F. in the cylinder above the piston where the oil is readily consumed. The first condition results in more or less decomposition and blackening of an unstable oil so that good results can hardly be expected when such an oil finally gets into the cylinder. The second condition must finally result in the more or less complete combustion of the oil as no oil could stand the excessive temperatures within the cylinder, but doubtless the oil remains partly unconsumed for a somewhat longer period than generally supposed. This would be due to the fact that the metal on one side of the oil film is a good conductor of heat and the oil itself is a poor conductor of heat, consequently the layer of oil next to the metal is partly protected from the heat by the outer layer of oil. This could not result in delaying actual combustion of the oil very long, but a fraction of a second's delay means the difference between actual lubrication and an absence of lubrication. When the oil finally burns, little carbon residue should be formed.

Except for the smaller high-speed pistons, as in automobile engines with small cylinders, the oil seal is relatively as important as actual lubrication and should be so considered. In fact, with a proper oil seal formed on the piston rings, sufficient lubrication will usually result.

Automobile Engines.—See chapter on Automobile Lubrication.

Stationary Gasoline Engines.—The oil used should ordinarily have a flash test of about 400° F., and should preferably be a straight distillate (viscous neutral). This mineral oil distillate may be blended with a very small amount of filtered cylinder stock, or well-refined cylinder stock, for use in heavy engines. Distillation of the oil should therefore show very little carbon

residue unless the oil is for extra large engines which require an extra heavy oil. The gravity is preferably, but not necessarily, above 26° Bé., though oils of any gravity may be used successfully if of the proper viscosity.

Oils which turn black on heating to their flash points for 15 minutes or show considerable sediment on subsequent standing will tend to form excessive amounts of carbon in use (see Heat Test). All oils show some darkening when heated to high temperatures.

Medium oils of 220 to 270 viscosity at 100° F. are suitable for small gasoline engines. For large gasoline engines heavy oils of 250 to 450 viscosity should be used. For engines operating in cold climates the cold test should be sufficiently low to meet practical conditions. Engines having force feed can use the higher viscosity oils to advantage, while the high viscosity oils are required for air-cooled engines.

Gas Engines.—The regular medium and heavy oils just mentioned are suitable for explosive gas engines.

Railroad Section Cars.—In these cars the oil is usually fed by mixing with the gasoline. An oil of at least 350 viscosity at 100° F. is required. Usually about 5 per cent. of the oil is added to the gasoline.

Motor Boats.—The engines are either two-cycle or four-cycle. For the two-cycle engines, medium motor oils of 200 to 270 viscosity at 100° F. are required. Where the oil is fed by mixing with the gasoline an extra heavy oil of 350 viscosity or over is necessary. For the four-cycle engines a somewhat heavier oil should be used than is necessary for the two-cycle engines, such as a medium oil of 220 to 350 viscosity, depending on the size of the engine cylinder. Where the oil is fed separately from the fuel a thinner oil can be used than with automobile engines on account of the efficient water cooling.

Motorcycle Engines.—The cylinder oil is fed by mixing with the gasoline or by some other method. Usually about 1 pint of the lubricant is added to 5 gallons of gasoline. The oil should

be a heavy or extra heavy motor oil of 350 to 800 viscosity at 100° F. Such an oil is suitable for all types of feed.

Gasoline Tractors.—Such tractors usually require heavier cylinder oils than the correspondingly rated automobile engines, on account of the continuous heavy duty required of tractors. Oils of about the grade specified for stationary gasoline engines above work satisfactorily.

Kerosene Engines.—Explosive engines using kerosene as fuel require heavy oils for lubrication. Owing to the necessity of pre-heating the fuel charge and the introduction of water into the cylinder to aid combustion, the consumption of oil is heavy. The temperature of the gases rises to nearly 3,000° F., while the temperature of the cylinder walls and piston head ranges from 300° to 800° F.

Suitable oils for kerosene engines should have a viscosity of 450 to 650 at 100° F. and a flash test of 400° F. The viscosity of these cylinder oils might preferably be taken at 210° F., as the oil in the crank-case is usually kept this hot, but of course a correspondingly lower figure for the viscosity would then be required. A suitable oil can be made by blending a large amount of cylinder stock of good grade with a suitable heavy distillate. Where the engine is constructed for using water in the cylinder with the fuel, the effect is to reduce the amount of "carbon" which would otherwise be formed by such a heavy oil and at the same time to keep the remaining carbon in such a condition that it is continually removed through the exhaust.

Much of the difficulty experienced in lubricating kerosene engines has been due to lubricants of too low viscosity. The introduction of water into the cylinder makes a different condition from that present where no water is introduced as in the regular gasoline engine. Much of the kerosene is burned in a finely atomized condition instead of being actually exploded.

Kerosene Tractors.—The same cylinder oil is used as for kerosene engines above. For the lubrication of other tractor parts, medium (No. 3) cup greases are suitable for the various cups and for the axle bearings. The transmission is lubricated with

transmission oil or a suitable cylinder stock of 175 viscosity at 210° F., or with a semi-fluid gear or transmission grease. The same dark grease may be used on the rear axle bearing if desired.

Regular and systematic cleaning of the cylinder and all wearing parts will pay well in lengthened life of the tractor.

Aeroplane Engines.—On account of the extreme lightness of the motors, the high speeds, the air-cooling and the absolute necessity for the motor to operate continuously at full capacity, the use of only the highest grade oils is absolutely necessary. These are usually of the same type as the very best of the automobile motor oils. The gravity should be high (30° Bé.), the flash test well above 400° F., the cold test not more than 15° F., and the carbonization test at 250° C. (482° F.) for 2½ hours should show only a minimum amount of material insoluble in petroleum ether or light gasoline (see Heat Test). The oils should be straight mineral oil distillates, or heavy distillates mixed with only small amounts of well-filtered high-grade cylinder stock, and should show little carbon residue on distillation to dryness. These tests are to insure an oil which will give the minimum amount of carbonization in use, as carbon would not only reduce the capacity of the engine, but might cause the engine to stop with all the hazard involved.

The viscosity of the oil should be high, a heavy-bodied oil of 400 to 550 viscosity at 100° F. being required. Vegetable castor oil is used extensively for lubricating certain cylinders, as in the Gnome rotary motor. It can be used alone or in mixtures with distillates compounded with other fatty oils. Aeroplane engines can also be lubricated by feeding part of the lubricant mixed with the gasoline and part through the regular oiling system.

While many of the newer aeroplanes have water-cooled engines, and consequently require somewhat less oil than the air-cooled engines, the conditions in both types of engines are excessively high piston speeds, extra high pressures and temperatures, particularly for long flights.

Diesel Engines.—The Diesel engine does not operate on the explosive principle of the usual gasoline engine, but burns an

atomized liquid fuel. The air in the cylinder is compressed to a much higher degree than in the gasoline engine, so that it becomes heated above the ignition temperature of the fuel oil. The finely atomized oil is consequently ignited as it is introduced into the cylinder toward the end of the compression stroke. Any liquid fuels, even heavy distillates can be readily used. The engines are usually built in large units and operate with a low fuel consumption for the power developed. Fuel oils can be burned which are not suitable for use in other internal combustion engines.

The lubrication is usually by a forced-feed or a circulating system. For the cylinders, use a medium or heavy automobile oil of 250 to 300 viscosity at 100° F. This oil should have a flash of 400° F. or over and should ordinarily have a low cold test, and a low carbonization test when heated for 2½ hours at 250° C. (482° F.). (See Heat Test.) On account of the high compression of the air in the cylinder (500 pounds per square inch) and the resulting high temperature before, during and after the combustion, the oil is subjected to such a high temperature that only a good grade of oil will stand up. In case heavier oils are required they can be prepared by blending a well-filtered high-grade cylinder stock with a larger amount of a high viscosity distillate. A 250 horse-power Diesel engine uses about one quart of oil per hour.

A high-grade oil as given above will usually meet all requirements so far as emulsifying is concerned. In certain Diesel engines where moisture is present in the cylinder the cylinder oil can be used compounded with 5 to 10 per cent. of a suitable animal or vegetable oil. It is preferable to use straight mineral oils wherever possible, as in the regular Diesel engines.

The oil used for the air compressors in connection with Diesel engines should in general meet the conditions stated above for Diesel engine cylinders. The oil should separate readily from water, should have a high gravity (above 30° Bé.), and should be a straight distillate of 200 viscosity or over. The oil should be filtered, and only just enough oil should be used. Oils sometimes form acid by oxidation under the influence of heat, and H.

Moore (*Engineer,* 120, p. 176, 1915, and *Ch. A.,* p. 1093, 1916) has shown that this is somewhat dependent on the iodine number of the oil.

In connection with the fuel oil consumption for a Diesel engine, it is interesting to note that the Bureau of Mines (*Tech. Paper* 37) states that 1 pound of fuel oil will generate the same power that 2½ pounds of oil or 4 pounds of coal would generate in a steam turbine. It takes from 0.525 to 0.721 pound of fuel oil per brake horse-power for a Diesel engine.

CHAPTER VI.

AUTOMOBILE LUBRICATION.

A. MOTOR LUBRICATION.

Mechanical Considerations.—In any discussion of automobile lubrication, the conditions to be met in cylinder lubrication naturally receive first attention, owing to its importance and to the special difficulties involved.

The various designers and manufacturers of automobiles have adopted slightly or radically different systems of supplying the lubricant to the cylinder. The most usual systems are splash feed, force feed, circulating feed, and modifications or combinations of these separate systems. In the splash systems all or a large part of the lubricant is carried in the crank case and is splashed on or fed indirectly to the cylinder walls below the piston, any excess oil being wiped off by the piston and running back into the crank-case reservoir or sump. In the other systems the oil is either sprayed directly on the cylinder walls below the piston, or it is fed directly to the friction edge of the piston where it is needed.

In any case, the lubrication is effected by means of the oil which actually gets between the piston head and the walls of the cylinder. With the four-cycle engine, used in all automobiles, the pressure is higher in the cylinder than it is outside the cylinder during three of the cycles. This tends to prevent the oil entering the cylinder past the piston head, and also causes a tendency to press the oil from between the piston head and the walls of the cylinder. During the remaining cycle the pressure in the cylinder is lower than it is outside, consequently there is more or less leakage of oil into the cylinder above the piston head. Most of the oil entering the cylinder is thus introduced immediately before the compression stroke. This is the oil which does most of the work and causes most of the trouble in cylinder lubrication.

The conditions are not materially different whether the motor has four cylinders or twelve, the important conditions being the size and weight of the pistons and the clearance or fit of the piston rings. With the new V-type motors used on eight- and

twelve-cylinder cars, the lubricating system has to be more elaborately worked out to secure proper distribution of the oil, but this is a problem for the automobile designer rather than for the automobile user. Ordinarily a working idea of the size of the cylinder can be had from the horse-power capacity per cylinder.

Temperature Conditions.—While exactly the same amount of heat is developed in burning a given amount of the same gasoline completely, irrespective of the motor used, yet the temperature attained may be very different with different motors. Small cylinders have more cooling surfaces in proportion to their capacity than large cylinders, consequently the temperature of the cylinder walls is usually lower for small cylinders. Thus, the temperature of the cylinder walls of a twelve-cylinder motor will ordinarily be lower than the temperature of the cylinder walls of a four-cylinder motor of the same power.

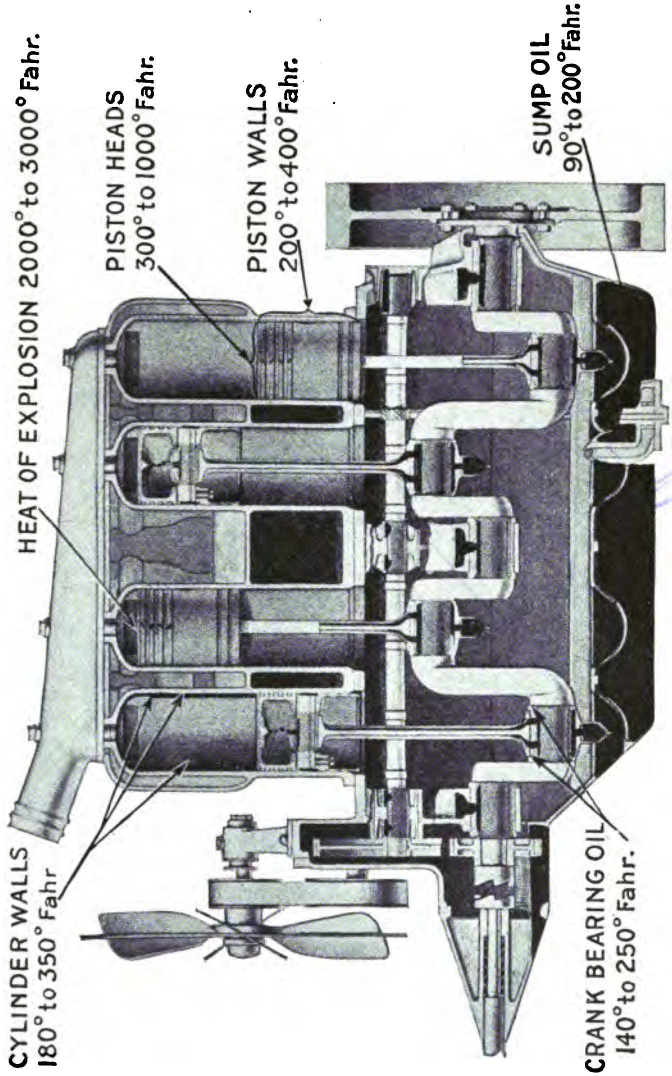
The following figures will give some idea of the temperature conditions in a water-cooled motor:

	Degrees F.
Oil in crank-case	100–225
Explosion temperatures	2,000–2,800
Temperature of piston	200–400
Temperature of piston head	300–900
Temperature of cylinder walls	200–350

It can be readily seen that the temperatures to which the oil on the cylinder walls and piston head is exposed will not only greatly reduce its viscosity but will rapidly vaporize and burn the oil. Fortunately the larger cylinders are always installed in a vertical position so that the weight of the piston does not come directly on the cylinder wall, otherwise much heavier oils would have to be used.

What Happens to the Oil.—With a properly working motor having close-fitting pistons, and using a suitable oil, only small amounts of oil get past the piston rings. Even with close-fitting piston rings, an oil of too low viscosity would get into the cylinder in greater quantity than necessary. With a thin film of oil on the cylinder walls and on the piston head, part of the oil

is vaporized and burned during each explosion, leaving a part of the oil still in working condition on the cylinder wall. Part of



Operating Temperatures of Motor Parts.
(By courtesy of Platt & Washburn Refining Co., New York.)

the oil may be burned without vaporizing. The small amount of carbon formed is readily blown out through the exhaust unnoticed.

If the oil happens to be thin, an extra amount of oil gains admission to the cylinder. This oil is vaporized and burned, or else burned without vaporizing, forming more carbon than the proper amount of oil would have done and at the same time leaving the cylinder and piston with insufficient lubrication. Oils of too low flash test would also vaporize unnecessarily fast and so reduce the quality of the lubrication.

If the oil happens to have sufficient viscosity, but is made by blending a large percentage of steam cylinder stock with some light distillate, as is often the case, the steam cylinder stock will not readily vaporize, but will accumulate on the piston head and on the cylinder walls. It will then be burned, or vaporized from the piston head, leaving considerable deposits. Steam cylinder stocks have not been vaporized in the process of manufacture and cannot be vaporized or distilled without partly breaking down with carbon formation. The heavy motor oils always contain considerable amounts of added steam cylinder stock.

In addition to the carbon formed by "cracking," carbon is also formed by the action of heat on the oils, the amount of such carbonization being determined by the chemical nature of the particular oil. The carbon deposits consist only partly of free carbon, the major part of the deposit being made up of grindings from the cylinder walls, road dust, and asphaltic or resinous matter formed by oxidation and polymerization of the oil under the intense heat.

Dr. C. E. Waters (*Tech. Paper No. 73* of the Bureau of Standards) states that the carbonization is due chiefly to this formation of asphaltic substances rather than to actual cracking. He recommends the heat test as an indication of the ability of motor oils to stand up under the conditions of use. Different oils heated for two or three hours to 250° C. (482° F.) show different amounts of material insoluble in petroleum ether. He does not consider longer heating necessary, but higher temperatures show even greater differences between "good" oils and "bad" oils. The amount of "carbonization" found for eight well-known brands of motor oil after heating for 2½ hours at 250° C. varied from 0.02 per cent. to 0.70 per cent. Oils which had been exposed for sev-

eral days to sunlight showed increased tendency to form carbon under heat. It is interesting to note that the oils which were tested for vaporization loss showed from 17 to 24 per cent. loss in three hours at 250° C. (482° F.), but this has no direct bearing on the amount of "carbon" formation.

The presence of an excess of oil not only tends to the formation of unusual amounts of carbon, but some of the excess oil or heavy residues from it may act to prevent blowing out much of the carbon that is formed and so aid in its accumulation in the cylinder. Too rich a gasoline mixture also tends to increase the deposition of carbon in the cylinder.

The Effect of Carbon Deposits.—The cylinders are designed for a certain charge and an optimum compression. While the designer has allowed for the accumulation of a small amount of carbon, yet any marked accumulation of carbon will not only cut down the capacity of the cylinder and so decrease the horsepower obtainable, but it will cause the compression to increase to such a point that the charge will be over-heated resulting in spontaneous ignition. Pre-ignition troubles may also result from highly heated carbon actually firing the charge. Some of the other effects are choking up of valves, spark plugs and piston rings. Carbon may result in "knocking," in abrasion of the cylinder and piston, in wasted fuel, in decreased power, or even in actual stoppage of the motor.

The Removal of Carbon Deposits.—The asphaltic matter usually makes up a large part of the deposit. Where the deposits are soft and powdery they can be readily removed mechanically. Harder deposits could be chiselled out. Deposits can also be burned out to advantage by the oxygen or oxy-acetylene process. Deposits can sometimes be loosened by leaving the cylinders full of kerosene over night and then operating the motor so as to blow out the softened accumulations through the exhaust. Various other light solvents besides kerosene have been used for this purpose.

Motor Oil Tests.—The most important single test is for the viscosity at 100° F. or at some higher temperature. The real lubricating value of the oil depends primarily upon its viscosity at the

temperature of use. The flash test in the open cup should be taken. Under certain conditions, the cold test, the fire test, the vaporization test and the color test should be made, but they are not usually important. The gravity is an indication of the source of the oil; if around 30° Bé., it is probably a Pennsylvania product and will probably retain its viscosity somewhat better under heat than other oils do. If the oil is not of Pennsylvania or similar origin it is well to allow a little extra viscosity as shown at 100° F. If the addition of excessive amounts of steam cylinder stocks is suspected, the distillation test can be made; a high carbon residue will indicate such additions. These stocks are added to cheap, light oils to make heavier motor oils, and they are also used as a legitimate addition to heavy motor oils to make extra heavy oils.

The carefully filtered oils may also be tested by heating to 250° C. (482° F.) for 2½ hours and determining the asphalt content by dissolving in petroleum ether and filtering off the undissolved asphalt. An asphalt content of 0.50 per cent. would indicate an unsatisfactory oil so far as carbon formation is concerned.

Cylinder Oil Specifications.—The oils should be straight distillates known as viscous neutrals, except the heavy motor oils which can be blended with a minimum amount of well filtered cylinder stock. The flash point should be approximately 400° F. or higher. An oil of proper flash consistent with its viscosity will usually be free from low boiling constituents and will give correspondingly good results in use. The gravity test may be of value in indicating the source of the oil, an oil of high Baumé gravity most likely being of Pennsylvania or similar origin. The fire test, the cold test and the color test usually give no added information so far as actual lubricating value is concerned. The oil when heated for 15 minutes to its flash point should not turn black and should show very little deposit on standing 24 hours. The oils should have been purified by filtration and not by acid treatment.

With light new cars, oil of 140 viscosity can often be used, but there is no advantage in using an oil below 160 viscosity at 100° F. A so-called "light" motor oil should have a viscosity of

about 180 to 200. Such an oil will usually lubricate all light cars in average condition, and all medium weight cars in good condition. It is preferable, however, to use the regular "medium" oil of 240 to 260 viscosity for the average medium weight car as the oil consumption will be considerably less than with the light oil and the resulting carbon formation will also be less. Cars in poor condition, as with loose piston rings, will require heavier oil for proper lubrication. For heavy trucks or heavy motors, an oil of 350 viscosity or over can be used. The heaviest oils offered for the very heaviest work rarely exceed 700 viscosity at 100° F. Heavier oils are desirable for air-cooled cars than for water-cooled cars. Knight motors require extra heavy oils.

Analyses of Some Motor Oils.—The following analyses show the properties of some oils actually in use for motor lubrication:

	Gravity	Flash(°F) Open cup	Viscosity	Remarks
Light motor oils:				
Sample No. 1...	26.6	405	162	
" No. 2...	27.0	390	183	
" No. 3...	30.0	415	195	
" No. 3a..	22.0	380	215	
Medium motor oils:				
Sample No. 4...	25.5	415	196	
" No. 5...	26.3	385	206	A blended oil shows 14.8% residue (liquid) on distillation.
" No. 6...	25.6	400	207	
" No. 7...	25.8	400	228	A blended oil shows 2.8% residue (liquid) on distillation.
" No. 8...	26.8	430	285	
Heavy motor oils:				
Sample No. 9..	24.5	420	262	
" No. 10..	29.0	420	310	
" No. 11..	27.2	430	435	

Analyses of a large number of motor oils made in 1917 show gravities ranging from 19.5° to 28.5° Bé., and viscosities as follows: Light motor oils 190 to 220 Saybolt at 100° F., and medium motor oils 250 Saybolt and higher. The heavy and the extra heavy motor oils have considerably higher viscosities, but do not

MOTOR OIL CHART.

The Viscosity figures indicate suitable oils for engines in average working condition. The minimum figures are for new cars, or for engines with close fitting piston rings, where the lubricating conditions are otherwise favorable. For summer use, and for engines in poor condition, the oils of higher viscosity are adapted. The figures represent the maximum ranges usually required for modern cars (1916 and 1917 models).

Automobile or truck	Viscosity of cylinder oil at. 100 °F.	Automobile or truck	Viscosity of cylinder oil at 100°F.
Abbott-Detroit	225-300	Liberty 6	250-275
Apperson, 6 & 8-cyl.	250-300	Locomobile, 6-cyl.	225-300
Atlas	225-300	Lozier, 6-cyl.	250-350
Avery	250-350	Mack	250-350
Benz	300-375	Marion, 6-cyl.	250-350
Blair	250-350	Marmon	275-375
Briscoe, 4 & 8 cyl.	225-300	Maxwell	220-275
Buick	220-275	Mercedes	300-375
Cadillac, 8-cyl.	225-300	Mercer	300-375
Cartercar	220-275	Metz	225-300
Case	225-300	Mitchell	225-300
Chalmers	250-350	Moline (Knight)	350-700
Chandler 6	220-275	Monroe	225-300
Chase (water-cooled)	225-300	National, 12-cyl.	250-300
Chevrolet	220-275	Oakland, 8-cyl.	275-300
Crow-Elkhart	225-300	Oldsmobile	250-300
Dart	225-300	Overland, 4-cyl.	220-275
Dayton	250-300	Overland, 6-cyl.	250-350
Dodge	225-300	Packard, 12-cyl.	250-300
Dorris	220-275	Packard, Comm.	275-375
Dort	225-300	Paige, 6-cyl.	250-350
Duryea	450-800	Pathfinder, 12-cyl.	250-300
Elgin 6	225-300	Peerless, 4, 6 & 8-cyl.	250-325
Empire	250-350	Pierce-Arrow, 6-cyl.	275-375
Federal	225-300	Pierce-Arrow, Comm.	200-250
Fiat	300-500	Premier	275-375
Ford	185-250	Pullman	220-275
Franklin, 6-cyl.	275-325	Regal, 8-cyl.	275-325
Haynes, 6-cyl.	275-350	Reo	250-350
Haynes, 12-cyl.	250-300	Saxon, 4-cyl.	200-250
Henderson	220-275	Saxon, 6-cyl.	250-325
Hollier 8	250-300	Selden	250-350
Hudson 6	250-350	Stearns-Knight, 4&8-cyl.	350-700
Hudson Super-Six	225-300	Stevens-Duryea	275-375
Hupmobile	250-350	Studebaker	250-350
I. H. C. (water-cooled)	250-375	Stutz	300-375
Indiana	250-375	Velie, 6-cyl.	220-275
Jackson 4 & 8-cyl.	225-300	Westcott	250-350
Jeffery 4 & 8 cyl.	250-350	White	250-350
King 8	225-300	Wichita	225-325
Kissel Kar	250-350	Willys-Knight	350-700
Knox	300-500	Winton	250-325
Lexington	220-275		

offer any regular basis for comparison so far as the viscosity at 100° F. is concerned. Where the working conditions are severe and a heavy oil is required, the tendency is to supply oils of higher viscosity than was formerly considered necessary under similar circumstances. In winter, it is necessary to use oils of low cold test to avoid difficulty in starting the engine, consequently oils of lower viscosity are needed in winter than in summer, as the heavier oils usually have relatively high cold tests particularly if from paraffin-base oils.

The tabulated analyses are not all for high grade oils. Owing to competitive conditions in the oil trade, and to the higher cost of the heavier oils, the tendency is to substitute low viscosity oils under the name "heavy" motor oils, and similarly for "medium" motor oils. While this may apparently be to the interest of the oil manufacturer, it is certainly not to the interest of the consumer. His interest demands an oil of somewhat too high viscosity in preference to an oil of too low viscosity.

Oil Consumption.—Most motorists waste their cylinder oil. With an oil of proper viscosity and with proper piston clearance as in new cars, the oil consumption can be cut to 25 per cent. of the average per mile consumption. Cars which normally require a gallon of oil for each 150 to 200 miles can be run with proper motor conditions for 600 to 800 miles on the same amount of a suitable oil. With proper oil-feed, carbon troubles would be a thing of the past. The blue smoke from the exhaust is not always due to a low grade gasoline; it is often due to an excess of cylinder oil.

With loose "leaky" piston rings a heavier oil is needed and more of it. More gasoline is also required and the results are in general less satisfactory. The proper clearance of pistons is not over 0.002 inch per inch of cylinder diameter. The crankcase reservoir should be cleaned out at frequent intervals. This becomes more necessary if there is leakage of contaminated and sooty oil past the piston head. A proper oil seal on the piston rings is as important as actual lubrication in saving power and in protecting the oil in the reservoir from contamination by hot gases and wastes from the cylinder.

The secret of successful motor lubrication is to keep the motor in good mechanical condition and use an oil of good (high) viscosity somewhat sparingly. It is not necessary to have an oil of quite as high viscosity for winter use as for summer use.

The two most important and necessary characteristics of motor oils are proper viscosity at the working temperatures and low carbon formation. The excessive high engine speeds, 2,600 to 3,400 revolutions per minute in some modern automobile engines, and the attendant high rubbing speeds in the cylinders make an oil of just the right viscosity absolutely necessary, otherwise the oil film will not have time to form and the power out-put of the engine will also be reduced.

B. GENERAL CHASSIS LUBRICATION.

Transmission Lubrication.—Where the transmission is suitably housed to retain oil, a good steam refined cylinder stock of 160 to 220 viscosity at 210° F. is a satisfactory lubricant. The lubricant should have enough body to adhere to and cushion the gears without wiping off from the teeth under the great pressure. Such an oil should be from 25° to 26° Bé., 30° F. cold test, 550° to 600° F. flash in the open cup and 600° to 675° F. fire test.

Where an oil does not have enough body, as in heavy cars and trucks, a transmission grease can be used. The true transmission greases are usually dark in appearance, being made from cylinder stocks, and are semi-fluid. The body of such a grease can be made sufficiently high for any properly designed transmission while the ability of the grease to stick to the gears is retained. If the grease is not semi-fluid, but stiff and heavy, the gears will cut "tracks" through it without being properly lubricated. If the grease is too thin, as would be the case if a thin oil were used in making the grease, the gears will not be cushioned properly.

Light cars are often lubricated with cup greases or similar light greases, either alone or mixed with steam refined cylinder stock. The light greases alone are hardly to be recommended as the greases have to be fairly stiff in order to do the work properly,

particularly if made from the usual grades of thin oils, but a stiff grease may fail to lubricate also by having the gears cut tracks through it.

Differential Lubrication.—A dark semi-fluid transmission grease of good body is suitable. The grease can be somewhat stiffer than described for the transmission. It should be made from cylinder oil stock. Cup greases should not be used, except possibly for light cars.

Some manufacturers use graphite or mica to assist in cushioning the gears. Excessive amounts of these substances act as cheapeners, although reasonable additions are legitimate.

Poorly designed or poorly cut bearings on heavy cars or trucks may require lubrication with a special heavy grease containing solid fiber, either asbestos or wood. Such a grease may reduce rattling, but it also increases power losses.

Worm Drives.—A special heavy gear grease is used on worm drives. The oil in the grease should be a suitable cylinder stock. For some drives an extra heavy cylinder stock of 220 to 250 viscosity at 210° F. is preferred instead of the grease. The use of tar or asphalt-thickened oils or greases is inadvisable for any of the gears of automobiles or trucks.

Roller Bearings.—For automobiles a medium to soft grade of fiber or cup grease can be used. For heavy trucks, it is necessary to use a tough, stringy grease made from a good cylinder stock. Fiber or sponge greases are preferable to cup greases as there is less tendency for the oil to separate from the grease. Gear compounds, which should only be made from sponge or fiber greases combined with heavy oil, are least likely to leak out.

The bearings of the rear axle are partly lubricated by the waste lubricant from the differential.

Greases loaded with much graphite or mica should not be used on the roller bearings in the wheels.

The Use of Cup Greases.—The chief use for cup greases in automobile lubrication is in connection with the various compression cups. For this work various consistencies are available, the most usual grade being a medium grease of No. 3 body.

Electric Road Vehicles.—For the transmission and gears a high-grade steam refined cylinder stock of 170 to 240 viscosity at 210° F. is suitable. The oil should have a fairly low cold test for winter use. Such a high viscosity oil will have sufficient adhering power to cling to the gears under pressure. In the rare cases where there is a tendency for the oil to work out, a thin, semi-fluid gear grease made from a high-viscosity cylinder stock can be used successfully. For general lubrication of the electric motors, etc., an oil of 300 to 350 viscosity at 100° F. can be used.

ADDITIONAL REFERENCE.

Bryan on "Motor Oils," *J. Am. Soc. Mech. Eng.*, 37, p. 293.

CHAPTER VII.

THE LUBRICATION OF ELECTRICAL MACHINERY.

Dynamos and Motors.—Most of these machines are equipped with ring-feed bearings, or with circulating feed. The usual conditions are high speeds and a fairly high operating temperature due to the heat generated by the electric current in the adjacent coils. The function of the oil is to give sufficient lubrication and to aid in cooling the bearings. Since the oil is used over and over again, a thin oil is decidedly preferable. Such an oil circulates more readily and permits the impurities to settle out more quickly.

Where the oil-cooling reservoir is not sufficiently large an oil of higher viscosity becomes necessary. Such an oil is more likely to form gummy material and give trouble than would a thinner oil kept at the proper temperature by an efficient cooling system. In starting a dynamo or motor, particularly the larger machines after long standing, the bearings can often be hand-oiled to advantage. The oiling-rings should be regularly inspected to see that they are revolving and so feeding the oil properly.

For lubricating the bearings of very small machines heavy spindle oils or non-viscous neutral oils can be used. These oils should have a viscosity of 70 to 110 at 100° F.

For small dynamos and motors, of 5 to 35 horse-power, viscous neutral oils are required. Engine oils of good grade and light automobile oils are suitable. The oils should preferably be straight distillates purified by filtration rather than by chemical treatment, and of low enough cold test to meet the conditions of use. The gravity of the best oils will ordinarily be above 30° Bé., but good oils can be had of 27° Bé. The flash point will be above 380° F., the cold test below 20° F., and the viscosity 140 to 180 at 100° F. The oils should be free from gummy or tarry matter as shown by the gasoline test.

For large dynamos and motors, over 50 horse-power, viscous neutral oils of 160 to 220 viscosity at 100° F., are suitable. These oils should preferably be straight distillates, have a flash test of

400° F., and be pure mineral oils as shown by the tests just given for purity.

Transformer Oil.—The function of a transformer oil is to act as a non-conductor, chiefly between the primary and the secondary coils, and to carry off the large amount of heat generated by reason of the electrical resistance in the coils. To be able to maintain the proper dielectric conditions, the oil must be absolutely free from acid, alkali and mineral salts, and free from any trace of moisture or mechanically suspended impurities.

Even one part of water in 100,000 parts of oil greatly reduces the dielectric strength of the oil. For use in high tension transformers the oil is subjected to a test at 30,000 volts. The suspended water is usually removed by filter-pressing; for example, through several hundred thicknesses of "blotting" paper. Water can also be removed by filtering through freshly burned lime. A simple method for testing for the presence of water in the oil is by shaking the oil with a little anhydrous copper sulphate. The white powder turns blue if there is a trace of moisture present. The anhydrous copper sulphate can be prepared for use by gently heating a little of the ordinary blue copper sulphate so as to drive off the water. The presence of water in any appreciable amounts can also be detected by heating a quantity of the oil in a test tube immersed in a boiling salt-water bath. If water is present in the oil a series of small bead-like bubbles will form on the surface of the oil where it is in contact with the tube.

In order to circulate freely the oil should be of low viscosity, preferably a non-viscous neutral of 80 to 120 or 140 viscosity at 100° F. The oil circulates by gravity or by means of a pump. The cold test should be below 20° F.

Since the oil is subjected to high temperatures almost continuously, up to 100° C., the flash should be over 340° F. The oil should not lose over 0.2 per cent. when heated at 100° C. (212° F.) for 5 hours, and should not contain asphaltic or tarry matter originally or after heating for several hours in the presence of air at 250° F. The gravity should be above 32° Bé.

Holde ("Examination of Hydrocarbon Oils," p. 81) states that

special rosin oils and heavier distillates, of approximately 300 viscosity, are also used. Rosin oils show much greater volatility than do the mineral oils, while the heavier mineral oil distillates show very little evaporation loss. The heavier oils show greater tendency to form the undesirable asphalt.

The "Report of the Sub-committee of the Institute of Electrical Engineers" on the suitability of an oil for a cooling-insulating medium gives a detailed account of the tests required. (*J. Inst. Elect. Eng.*, 54, p. 497, 1916; and *J. Soc. Chem. Ind.*, 35, p. 625; also *Chem. A.*, p. 2633, 1916.) For methods of making the evaporation test for transformer oils see Waters, *J. Ind. & Eng. Chem.*, pp. 394-398, 1913.

Electric Elevators.—For suitable oils for lubricating the motors, see specifications under electric motors of the proper capacity. The worm-gears can be lubricated with a steam refined cylinder stock of 170 to 220 viscosity at 210° F. Heavy, dark gear greases when not too stiff, or similar semi-fluid greases made by blending fibre or sponge grease with cylinder stocks can be used. For the compression cups a medium grease will answer if the grease contains an oil of sufficient viscosity. Small additions of graphite or of high-grade mica may be beneficial in the worm-gears.

For lubricating the metal cables and for preventing rusting, a very heavy engine oil distillate of 300 viscosity at 100° F. can be used, or a good cylinder stock, or cylinder stock blended with a distillate. The guides can be lubricated with similar heavy oils.

Rotary Converters.—The same type oil, or slightly heavier oils are used as for heavy dynamos and motors.

Vertical Electrical Generators.—These are mounted on a water-driven shaft which ordinary floats on an oil film maintained by a circulating force-pump. The oil should have the same general characteristics as specified for large dynamos and motors and should have a viscosity of at least 200 at 100° F.

Electric Railways.—The various bearings and journals are likely to become badly contaminated with dirt and grit sucked up from the road-bed. Regular, systematic inspection and regular

cleaning are necessary to prevent destruction of the bearings and to keep the packing in place so as to feed the lubricant to each bearing. The waste should be well moistened, but not soaked, in order to lubricate without wasting the oil.

The motor axle bearings and the bearings of the armature are subjected to considerable heating from the electric current and so should preferably be lubricated with a heavy engine oil of 280 to 400 viscosity. The flash test should be approximately 400° F. and the cold test 10° or 25° F. depending on the season and the climate.

Air compressors (see Index) are lubricated with a good light cylinder stock or cylinder oil.

For lubricating the journals a cheap car oil is satisfactory. Suitable black oils or car oils should have the following characteristics: For summer, 80 to 90 viscosity at 210° F., 300° to 325° F. flash test and free from excessive amounts of tarry sediment; for winter, about 65 viscosity at 210° F., 275° to 300° F. flash test, 10° F. cold test, and free from excessive sediment (not over 5 per cent. by the gasoline test).

It has been customary for some of the oil companies to rate black car oils on the basis of their viscosity at 130° F.

Street railways are often furnished lubricants on a per mile basis, but this is not always to the interest of the railway companies.

For the motor gearing of electric railway cars, heavy greases of high melting point are used. These greases should be made from heavy oils so as to cling to the gears properly. Sometimes greases containing a heavy residuum combined with tar are used on account of their ability to cling to the gears under the conditions of use, but the solid grades of this grease, similar to "hot neck" greases for rolling mills, are too thick for advantageous use on car gears. One reason for using such greases in preference to regular gear greases, is on account of the higher cost of the regular gear greases.

Curve greases, for application to the tracks, are made from crude, heavy residuum, from various grades of tar or pitch, or from combinations of tar and residuum.

CHAPTER VIII.

THE LUBRICATION OF STEAM CYLINDERS AND STEAM ENGINES.

Saturated Steam Conditions.—When steam is generated in a closed space, as in a steam boiler, the pressure rises to a definite point corresponding to the temperature of the steam. This is the usual type of boiler, the steam pressure being automatically released by a safety valve whenever it reaches a predetermined maximum. The temperature of saturated steam is exactly proportional to the pressure, so if the correct, effective gauge pressure is known the temperature can be read off by means of a table such as the following:

Effective gauge pressure (lbs. per sq. in.)	Temperature °F.	Effective gauge pressure (lbs. per sq. in.)	Temperature °F.
10	238	120	350
20	260	130	356
30	276	140	360
40	288	150	365
50	297	160	370
60	307	170	375
70	316	180	379
80	323	190	383
90	332	200	387
100	337	225	397
110	344	250	406

It will be noticed that, even with the highest pressures used, no importance need be attached to the flash point of cylinder oil for use with saturated steam as practically all cylinder oils now offered for sale flash above 500° F.

The viscosity of the oil is important as well as the amount of fixed oil and the method of feeding the oil to the cylinders. Pressures below 60 pounds are usually called low pressures, while high pressures refer to pressure of 125 pounds per square inch and over.

Superheated Steam Conditions.—Superheated steam is steam which has a higher temperature than corresponds to its pressure, owing to having been subjected to direct heating after being gen-

erated in the boiler. The number of degrees the steam is above that of saturated steam at the same pressure is called the "degrees of superheat." The extra heating is usually accomplished by having a large number of small pipes making a number of turns in the firebox, the steam having to move through these pipes on the way from the boiler to the steam chest. The turns in the pipes are necessary in order to "break the core" of the steam which is moving at an extraordinary velocity and so insure its coming into contact with the hot pipe.

The economy in the use of superheated steam comes from the facts that a very large amount of heat is required to change water into steam, and less heat is required to raise steam one degree than to raise water one degree. Steam, like any other gas or vapor, expands rapidly when heated. This expansion of the steam in the pipes in the firebox does not result in increased pressure over that in the boiler, but has the effect of increasing the volume of the steam and so raising the capacity of the boiler equipment.

Superheated steam has many advantages over high pressure saturated steam, especially for locomotives. The temperature of superheated steam may rise to 600° or 700° F. While the steam may reach such temperatures for certain engines, at the moment of introduction into the cylinders, the most usual practice is to give just a sufficient degree of superheat to insure the steam reaching the steam chest without condensation. Normally, the steam is introduced into the cylinders with more or less superheat. The actual cylinder pressure is more nearly the boiler pressure than with saturated steam as the loss of pressure from condensation is largely overcome. With saturated steam, condensation not only acts to lower the pressure but also to waste steam which has already been generated before it has had a chance to do useful work.

In any case, whatever the degree of superheat, the steam may be so reduced in temperature during its expansion in the cylinder, by reason of work done and loss of heat through conduction and radiation from the cylinder, that condensation takes place and a wet steam results. Most of this water is ordinarily vaporized

during the exhaust or it is vaporized by the subsequent inrush of more superheated steam. With a high degree of superheat, compound cylinders are used, the high-pressure cylinder working dry and the low-pressure cylinder fed by the exhaust steam, working wet as a regular saturated steam cylinder.

The conditions in a superheated steam cylinder as compared to a saturated steam cylinder, are higher working temperature, higher working pressure, and dryer steam for the former. In order to meet these conditions, a higher viscosity oil is required with a better flash and fire test. Except in rare cases compounded oils are necessary. Superheated cylinders and valves, except on locomotives, require very little fatty oil in the cylinder oil.

Methods of Applying Cylinder Oils.—The kind of cylinder oil to use is largely dependent on the method of lubrication. Where the oil is warmed before pouring into the lubricator and where the oil in the lubricator is kept warm by the aid of steam or condensed water, a low cold test is of slight importance ~~except for convenience in handling~~.

In the hydrostatic or sight-feed lubricator, such as the widely-used Detroit or similar lubricator, the oil floats on warm water supplied by condensation from a vertical steam pipe, the condensed water in the vertical pipe serving to force the oil through a small tube into a sight-feed glass. Here the oil feeds up through water, drop by drop, then goes by a short pipe well into a special steam pipe leading to the cylinder or steam-chest. The passing steam catches the oil drop and shoots it to the steam chest in a finely atomized condition. The cylinders and valves may be lubricated by separate pipes or by the same pipe. If the oil has too high viscosity for the steam pressure available it will not be properly atomized for good lubrication. Low flash oil and oil high in fatty oils seem to be more completely atomized than high flash oils or straight mineral oils.

The sight-feed glass should be kept clean so as to feed perfect drops, and the cup of the lubricator should be frequently drained and cleaned. In starting the lubricator, the oil feed should not be opened until the oil in the cup has reached a proper working temperature, which is usually about 140° to 150° F. Also the

feed water in the vertical pipe should be sufficiently high to feed the oil. The rate of feed is judged by the number of drops of oil per minute. Cylinder oils vary from about 3,000 to 6,000 drops per quart of oil, depending on viscosity, amount of tar, etc., as well as on lubricator conditions.

Detroit Improved Standard Lubricator.
(By courtesy of Detroit Lubricator Co., Detroit, Mich.)
The principle employed in the hydrostatic lubricator is simple and positive. Steam being admitted into pipe "B" and condenser "F" condenses, thus forming a column of water which exerts a pressure equal to its head plus the difference in specific gravity between oil and water, through the tube "P" on the oil in reservoir "A." By this excess pressure the oil is forced from reservoir "A" through the tube "S" and sight-feed nozzle "N" into the sight-feed chamber "H." The sight-feed chamber being filled with water, the drop of oil floats to the top and passes to the point to be lubricated through the passage "T" and support arm "K."

Force-feed lubricators, worked mechanically by the moving parts of the engine, are not so generally used as the sight-feed lubricators, but heavier oils can be fed with the force-feed lubri-

cators. These lubricators can be used advantageously with heavy engines for intermittent service, the flow of oil stopping and starting automatically when the engine is stopped or started. They can also be used to advantage with variable speed engines. The manufacturers of mechanical lubricators claim that better lubrication is obtained by feeding a little of the oil at each stroke of the piston than can be had with the usual hydrostatic lubricators.

Cylinder Stocks.—For the methods of manufacture and for actual analyses of cylinder stocks see Index. These stocks are straight undistilled petroleum products. The light oils present in the original petroleum have been removed, usually by steam distillation, and the residue left in the still is purified by more or less complete filtration. The residues from the distillation of many crudes are unsuitable for making cylinder stocks, and are not so used, but are used as car oils, fuel oils, etc. Sometimes a low viscosity cylinder oil is made by cutting back a heavier cylinder stock with a very limited amount of heavy engine oil, but such a blended oil will have a low flash test. The cylinder stocks are treated for the removal of paraffin so as to improve the cold test. However, high viscosity stocks, as for valves, will have a pasty character particularly in winter.

Western stocks have a lower gravity than Pennsylvania stocks, so, unless Pennsylvania stock is used, a high gravity stock should not be required. Much of the difficulty in using western stocks comes from insisting that they comply with the gravity standard of Pennsylvania oils, whereas the important consideration is the viscosity of the oil at 210° F. and higher. Pennsylvania stocks have a gravity of 25° to 29° Bé. with viscosities ranging from 90 to 250 or over at 210° F. The higher viscosity oils (170 and over) are rarely filtered. Western stocks have gravities as low as 18° Bé. and lower flash tests than Pennsylvania stocks.

The most important consideration is the viscosity at the working temperatures. The working temperatures are about 140° to 150° F. for the lubricator, and above 210° F. for the cylinder. While the viscosity in the cylinder is lower than the viscosity as determined at 210° F., yet the working viscosity in the cylinder

is directly proportional to the viscosity taken at 210° F, and so oils can be correctly compared and judged on that basis.

In order to feed properly, the stocks should be free from tar. Green stocks are usually free from excessive amounts of tarry matter, but all stocks should preferably be tested by the gasoline test. Any asphaltic or tarry matter will fail to dissolve in the gasoline and will settle out so that it can be readily seen.

Cylinder Oils.—Cylinder oils are made by compounding (mixing) cylinder stocks with animal or vegetable oils. Cylinder stocks are never used alone for lubricating saturated steam cylinders except where the condensed water is to be used again for some purpose, and are rarely used alone for lubricating superheated steam cylinders, at least in this country. A certain amount of fixed oil (fatty oil) is necessary to keep the wet steam from displacing the oil from the friction surface of the cylinders and valves. A straight mineral oil will not form or maintain an oil film on metal in the presence of hot water, that is, it will not "wet" the metal, and so will not lubricate. Fatty oils will "wet" metal in the presence of hot water and they have the property of keeping this valuable characteristic even when mixed with mineral oils.

Varying amounts of fixed oils are required, ranging from 2 to 12 per cent. or over, the lower per cent. being sufficient for very dry steam and the higher per cents. being required for very wet steam, as is present in low-speed cylinders. The usual cylinder oils contain less than 12 per cent. of fatty oil, the amounts ordinarily present being from 4 to 10 per cent.

Practically all kinds of animal and vegetable oils have been used at times for compounding cylinder oils. The most generally preferred is tallow oil, but neatsfoot oil, lard oil, degras, degras oil, rape oil, blown rape oil, cottonseed oil and even linseed oil have been used. The animal oils are preferred on account of their non-gumming character. Rape oil is popular abroad, and blown rape oil is used as it has a high viscosity which makes the viscosity of the compounded oil not much lower than the viscosity of the stock from which it was compounded. The addition of

fatty oil greatly lowers the viscosity of the cylinder stock to which it is added, even more than would be expected.

Excessive amounts of fatty oils, above that actually required, should not be added to cylinder stocks as the fatty oils break down somewhat under the action of steam, forming free fatty acids which attack the metal of the cylinder. Carefully compounded oils do not give any trouble in this particular.

The oils used for compounding cylinder oils should be "acidless," as acidless tallow oil; that is, they should contain less than 2 per cent. of free acid calculated as oleic acid.

If the exhaust steam is to be condensed and used over again it is important that the amount of fatty oils be reduced to a minimum so that the oil can be separated from the water readily. This is true in the case of cylinder oils for ice plants and for marine engines which are often operated with straight cylinder stocks.

It may be said that the high viscosity cylinder stocks have better adherence to hot, wet metal than have lower viscosity stocks, and so require no more fixed oils than do cylinder oils for lower pressures. The high-flash, high-viscosity oils are more difficult to atomize, but proper location of steam pipe and proper installation of the lubricator will result in good atomization with the higher pressure steam.

For superheated cylinders, oils are compounded from high fire-test, high viscosity stocks and 3 to 11 per cent. of animal oil, usually tallow oil. As much as 11 per cent. is not usually required for stationary engines, but may be in locomotive practice on account of greater condensation from cooling in winter or to make possible the lubrication of the low-pressure cylinders of compound engines with the oil carried by the exhaust steam from the high-pressure cylinders. The viscosity of the finished oil is rarely as low as 140, and is usually between 160 and 220 at 210° F. Cylinder oils for saturated steam have viscosities from 100 to 220 at 210° F.

Filtered cylinder oils are not usually required for either saturated or superheated steam cylinders.

Analyses of Some Cylinder Oils.—The following analyses were recently made by the author:

No. of oil	1	2	3	4	5	6
Kind of oil	Pasty filtered stock	Bright filtered stock	Bright filtered stock	Steam refined stock	Filtered railroad super-heater	Filtered railroad saturated
Baumé gravity....	22.0	23.1	26.2	25.6	25.5	26.0
Flash test (°F) ...	(550)	510	545	585	535	(530)
Viscosity at 150°F.	—	458	435	—	—	406
Viscosity at 210°F.	183	138	141	168	180	128
Fatty oils (%)....	1.5	(0.4)	2.6	0.9	11.2	10.6
Iodine No. (Hanus)	—	—	12.0	—	21.7	22.1
Maumené No. (°C.)	3.5	3.0	4.5	4.5	11.5	11.0
Volatile at 350 °F. in 2-hours (%)..	1.0	—	1.0	0.8	1.5	1.7
Acid as oleic (%) .	—	—	0.22	—	—	1.06

No. of oil	7	8	9	10	11	12
Kind of oil	Dark low pressure	Low pressure	High pressure	Special low pressure	High pressure	Special low pressure
Baumé gravity....	27.0	22.5	24.5	25.0	22.4	22.6
Flash test (°F) ...	485	530	570	455	550	525
Fatty oils (%) ...	9.5	3.6	5.3	3.3	7.0	4.8
Viscosity at 150 °F.	281	465	696	341	666	463
Viscosity at 210 °F.	100	141	220	115	187	136

Sample No. 7 had a viscosity of 975 at 100°F., and 572 at 120°F.

Cylinder Greases.—These greases require special type lubricators so that the greases melt to oils before they are fed to the cylinders. These greases consist of high cold test cylinder stocks compounded with enough tallow, degras or solid fat to make them fairly firm at ordinary temperatures. Pasty cylinder stock of the valve oil type may be used or vaseline may be added to the "grease" along with the fats. These greases melt easily and lubricate substantially in the same way that the oils do and so would be tested for viscosity and amount of fats in the same way cylinder oils are. Excessive amounts of fats should be absent and no soaps should be present.

Poor Lubrication.—Indications of poor lubrication, either through insufficient amount of lubricant reaching the cylinder and valves or by the use of an unsuitable oil, are groaning of the valves and vibration, as in heavy Corliss engines and in engines used for air compressors. More oil should be used, and if this does not quickly correct the trouble, the valves and cylinders should be inspected for scoring or a heavier oil should be used. Poor lubrication is also indicated by difficulty in manipulating the valves, as in locomotives. The use of graphite in the cylinders or in the cylinder oil, or of a very little high-grade mica, has been found to improve the tendency of the valves to stick.

Scoring and groaning may be due to poor lubrication for which the oil is in no way responsible, but may sometimes be traced to adjustment of the lubricator which results in insufficient lubricant reaching the cylinders, or by poor adjustment of the pipe conveying the oil into the steam pipe so that the oil is not properly atomized by the steam. Any scoring of the cylinder would naturally continue to prevent proper working regardless of the character of the subsequent lubrication. The proper remedy would be to overhaul such cylinders promptly.

Good lubrication is indicated by easy working of the valves, and by the presence of oil on the piston rods as evidenced by holding a piece of white paper against the rod. By removing the cylinder head, proper lubrication will be shown by the presence of the oil film and by the absence of appearance of wear.

Cylinder Deposits.—These deposits may form on account of mineral matter brought over from the boiler by "foaming," especially in connection with the use of excessive amounts of boiler compound. In this case they should contain large percentages of lime and magnesia compounds, or compounds derived from the boiler treatment.

Deposits may be due to wear from insufficient clearance of the rings or from allowing the edges of the rings to get sharp. In this case a magnet will show a large amount of metallic iron present.

Where the cylinder oil is to blame, considerable carbon is likely to be present from cracking of the fatty oils present, and ex-

cessive amounts of iron rust or iron oxide show the action of fatty acids on the metal. The fatty acids could be present in the original oil or be formed from excessive amounts of fatty oils in the cylinder oils under the action of steam. Iron oxide, however, may at times come over with muddy water from the boiler. Fatty acids are active at high temperatures and rapidly corrode iron and other metals.

If an asphalt base mineral oil has been used asphalt may have been formed by the heat, in which case an analysis of the deposit would show considerable organic matter insoluble in gasoline. With superheater engines, particularly locomotives during "drifting" immediately after a hard pull, the admission of oxygen to the hot cylinders may carbonize the oil remaining in the cylinder.

General Engine Lubrication.—For lubricating the moving parts of steam engines, other than cylinders and valves, a good grade of engine oil should be used. This oil is preferably a straight mineral oil distillate of 400° F. flash test, 27° to 31° Bé. gravity, and a viscosity of 180 to 250 at 100° F. For large engines with circulating oil systems, the viscosity need not usually be over 220 at 100° F. as an oil of lower viscosity can be used with a circulating system which floods the bearings than without a circulating system where the oil must be fed sparingly. The excess oil tends to cool the bearings and so maintain the viscosity of the oil.

As more or less water comes in contact with the oil it is necessary to separate out this water in the oil-filtering process. A good quality of filtered oil should therefore be used, and it should be protected in every way from other contaminating oils. If an oil too high in fatty oil is used in the steam cylinder, some of this oil may finally work into the circulating oil supply and cause it to emulsify with the water to an objectionable extent. For large engine installations it is desirable that oils be tested for emulsification with water, and an oil chosen which shows little emulsification.

Marine Engines.—Marine engines are often operated without any lubricant to the cylinder other than the condensed water, where the water is needed for further use. Upon entering port

cylinder oil is fed to the cylinder to prevent the idle cylinder from rusting. Small amounts of steam refined stocks, without the addition of fatty oils, can sometimes be used satisfactorily, but the addition of 2 or 3 per cent. of acidless tallow oil improves the lubrication. By using an oil of low viscosity (125 to 140 at 210° F.), of low fatty oil content, and low acidity, excessive emulsification of the oil with the exhaust water can usually be prevented.

For superheater marine engine cylinders, straight high viscosity refined cylinder stocks may be used, either alone or compounded with not over 3 per cent. of acidless tallow oil. The finished oil should have a viscosity of 180 to 250 at 210° F.

For general engine lubrication, it has been a long established custom to use a heavy engine oil compounded with 20 to 30 per cent. of blown (thickened) rape oil. This increases the viscosity of the oil to over 350 at 100° F. It is important that the oil be free from fatty acids and it is sometimes advantageous to add some other fatty oil in addition to the rape oil to overcome the tendency of blown rape oil to separate from the mineral oil.

Steam Turbines.—Lubrication is usually by a gravity or force-feed circulating system which makes it possible to use a thin oil. High-grade, pale engine oils, known as viscous neutrals, are generally used. They should have a gravity of over 30° Bé., be straight mineral oil distillates free from acids, and have a flash point around 400° F. Where an asphalt base oil is used the flash and gravity will not be so high. The oil should always be tested for its emulsifying properties as the oil should separate readily from water in practice.

In order to continue to separate from water properly and maintain a suitable viscosity without the development of acidity, the oils should be practically free from sulphur. The nature of the sulphur compounds is important. For examples of oils which thickened and changed in use, see Conradson, *J. Ind. & Eng. Chem.* p. 179, 1910, and Herschel, *Tech. Paper* No. 86 of the Bureau of Standards, pp. 35-36.

The oils should be non-carbonizing when tested as for motor

oils and should be free from undistilled residue. In practice the amount of oil in the circulating system should be ample to prevent any great increase in the temperature of the bulk of the oil. Sulphur and continued high temperature of the oil tend to develop acids which would attack the bearings and cause emulsification. The maximum working temperatures are ordinarily from 130° to 140° F., but according to Herschel some of the more recent turbines run at 175° F.

The oils used have from 120 to 170 viscosity at 210° F. The most important single test, after the viscosity test, is the emulsification test which gives a better indication of the behavior of the oil in use in a circulating system than can be obtained by any other physical or chemical tests. (See Emulsification test pages 117-121, also pages 29-31.)

ADDITIONAL REFERENCES.

F. L. Fairbanks, address on "Lubrication of Bearings and Cylinders," *Power*, 42, pp. 805-808, 1915.

Richardson and Hanson on "Valuation of Cylinder Oils," *J. Soc. Chem. Ind.*, 24, 315-319, 1905.

CHAPTER IX.

THE LUBRICATION OF STEAM RAILWAYS.

Locomotive Cylinders and Valves.—The cylinder oils are applied to the cylinders, valves and air compressor by means of a triple feed, and sometimes by a five-feed, sight-feed lubricator. The usual method is by means of a triple-feed lubricator feeding to the slide valves or steam chest on either side, and to the air compressor, the cylinder getting its lubrication more or less indirectly from the steam chest.

The conditions outlined in the previous chapter for cylinder oils for superheated and saturated steam apply also to the lubrication of locomotives. The opportunity for cooling of steam pipes and cylinders is much greater with a rapidly moving locomotive than with a stationary engine, particularly in winter, and so, with saturated steam at least, sufficient condensation is likely to occur to make the use of the minimum amounts of fatty oils inadvisable. Good locomotive cylinder oils contain from 7 to 12 per cent. of saponifiable or fatty oil so as to be reliable under all working conditions, the most usual amount being around 10 per cent. There are doubtless conditions for small, or poorly operated engines, where as much as 15 per cent. fatty oil will be needed, but this is the exception.

Saturated Steam Cylinders.—In saturated steam practice it is unnecessary to stress a high flash or fire test oil, as practically all oils have sufficiently high tests to meet all requirements, and unnecessarily high flash or high viscosity oil does not atomize with the steam quite so readily as does somewhat lower flash oil. It is usually a mistake to use oils of high viscosity for saturated steam locomotives, oils from 115 to 135 viscosity at 210° F. meeting all requirements for successful lubrication and low oil consumption. Cylinder oils, in order to feed properly, should be free from tar as shown by the gasoline test. A cold test of 50° or 60° F. is usually satisfactory. If western oil is used the gravity should not be seriously considered, as an effort to get a certain gravity oil would result in the sacrifice of some more

vital property, for example, a lowering of the viscosity shown at 210° F.

It is customary to use the same oil for the cylinders and the air compressors. A high flash oil of the cylinder oil type is necessary for locomotive air compressors as they are air-cooled which permits compression temperatures of 500° F. or over.

Cylinder Deposits.—These may be caused by foaming in the boiler, as with excess of boiler compound or with certain waters containing much dissolved matter, in which cases the deposit will show much lime and magnesia, and sometimes iron oxide from muddy water. Scoring of the cylinders will be detected by metallic iron in the cylinder deposit as evidenced by a magnet. The oil may be to blame in certain rare cases, either by decomposing under the heat with carbon and asphalt formation, or by the breaking up of the fatty oils which yields corrosive fatty acids. The latter condition may result where the oil is compounded with fatty oil which is not "acidless" or where too large a percentage of fatty oil is used in compounding, the valves, etc., being pitted or corroded with the formation of much red iron oxide or rust.

With superheater locomotives, the practice of "drifting" or coasting with air admitted to the cylinders, particularly just after a hard pull, will result in actually burning up the oil and forming a carbonaceous residue. This leaves the cylinder and valves without lubrication after steam is re-admitted to the cylinder as some time is required to form a new film of the oil. Burning of the oil does not seem to take place much below 550° F. or in the presence of steam, so if the air is not introduced until a moment or two after the severe pull is ended, the oil is less likely to be destroyed. The introduction of the hot front end gases at any time is likely to consume the oil as well as introduce cinders and ashes which destroy the oil and form very undesirable deposits. During drifting, the low-pressure exhaust steam could be used to advantage in the superheated cylinders.

Superheated Steam Cylinders.—The pressures are not necessarily any greater than with saturated steam cylinders, but the temperatures are much higher, possibly as high as 600° or 700°

F. at times. Consequently a large percentage of the oil is finally vaporized. Much of it is vaporized by the superheated steam after atomization in the steam pipe, in which case the oil vapor seems to "lubricate" the steam and condense on the walls of the cylinder during the cooling of the steam in the cylinder. While a high flash test is desirable, an unduly high flash or fire test will prevent proper atomization and volatilization of sufficient oil to give the best results. Superheated steam is dry and has no lubricating value as wet steam has.

Cylinder oils for use in superheated locomotive cylinders should be able to stand a good heat, say 5 or 6 hours in an air bath at 500° to 550° F. without developing material insoluble in gasoline. When an engine can run 50 or 75 miles on a pint of valve oil, as in general practice, the quality of the oil is much more of a consideration than the price per gallon. Excessive amounts of oil are not desirable.

On account of superheated steam being dry, and on account of the greater adhesive properties of the high viscosity petroleum oils, very small amounts of fatty oils are really necessary. However, it is customary to use from 5 to 10 per cent. of fatty oil, usually the latter amount in order to meet the varied requirements of locomotive service. There are likely to be times when the cylinders work wet. It is also desirable to lubricate the low-pressure cylinders in compound locomotives with the waste oil brought over by the steam from the high-pressure cylinders. For the lubrication of these low-pressure cylinders, the same amount of fatty oil is necessary as for other saturated steam cylinders.

The viscosity of superheater oils varies from 135 to 180 at 210° F. Saturated valve oils with viscosities of 135 to 140 at 210° F. will generally lubricate superheater valves and cylinders satisfactorily under normal conditions.

While the tendency is generally toward rather high pressures and a high degree of superheat in American locomotive practice, for example, 220-pounds pressure and 230° of superheat (equivalent to about 625° F. actual steam temperature), there are some types of locomotives using a low degree of superheat. These locomotives show only about 30° of superheat at

the cylinder which is about enough to insure the steam being dry at the time it enters the cylinder, consequently the lubrication conditions are practically the same as for saturated steam cylinders.

American practice is toward heavier locomotives, and more exacting service conditions with longer trains and heavier cars. The increase of superheater locomotives from almost none to some 20,000 in the last 10 years has rendered a more careful study of cylinder lubrication necessary.

Special Apparatus for Studying Cylinder Oils.—A valuable apparatus for studying the behavior of cylinder and valve oils with saturated and superheated steam has been devised by Dr. P. H. Conradson. For description of apparatus, method of operation, results obtained and discussion of results, see papers by Dr. Conradson in *J. Ind. & Eng. Chem.*, Vol. IV, pp. 744-745 (1912); *8th Int. Cong. of Appl. Chem.*, Vol. I, pp. 127-129, and Vol. XXVII, pp. 13-17; also address before the Cincinnati Railway Club, May, 1915.

This apparatus is essentially a small boiler equipped with gauges, superheater, thermometers, hydrostatic or sight-feed lubricator for feeding the oil when the steam has reached the desired temperature, a horizontal glass cylinder for observing the oil-steam mixture or for heating a weighed amount of oil in a dish, and a condenser for recovering the oil and steam. The steam rate is judged by the amount of condensed water.

The apparatus can be used with temperatures up to 1,000° F. which is 300° or 400° F. higher than required in the most exacting service conditions for superheater locomotives. Admission of air into the apparatus at 550° F. or higher shows the carbonization and destruction of oils which results from the practice of "drifting" or coasting with air admitted into hot steam cylinders.

Dr. Conradson says:

"It is interesting to note that cylinder oils containing rather a large percentage of saponifiable fats or fat oils generally come over at much lower temperatures than the main portions of the petroleum stock oils that are commonly used in compounding first-class cylinder oils.

"The cylinder oils may leave a residue in the dish at steam tempera-

tures below 700° F.; if so, such residue should give a clear solution in 90 cc. of 0.65 specific gravity (87° Bé.) petroleum ether (Pennsylvania) and show no precipitate on standing. At steam temperatures of 850°-900° F., all the oil has usually been volatilized with the steam; good oils should leave no carbonaceous or coky residue."

The accompanying table of comparative tests of five samples of cylinder oils, A, B, C, D, E, and F, a petroleum distillate, is of particular interest in connection with the study of cylinder oils in superheated steam. (From *8th Int. Cong. App. Chem.*, XXVII, pp. 13-17, paper by Dr. Conradson.)

	A. Fahr.	B. Fahr.	C. Fahr.	D. Fahr.	E. Fahr.	F. Fahr.
Flash point (open cup)	545°	550°	605°	595°	550°	365°
Burning point	610	530	695	680	630	415
Gravity at 60°F. Baumé	26.4	26.1	24.7	25.9	—	33.5
Sp. gr. at 15°C.	0.895	0.897	0.905	0.898	—	0.856
Color	Light	Dark	Dark	V. dark	—	Yellow
Gas. test bef. fire test	Good	Good	0.5 cc.	4. cc.	—	—
Gas. test after fire test	Good	Good	Good	3. cc.	—	—
Cold test flows	+55°F.	+32°F.	+45°F.	+34°F.	+30°F.	Zero
Saponifiable fats	Trace	Trace	Trace	Trace	15%	None
Vis. Saybolt at 212° F. (60cc.)	133 sec.	146 sec.	215 sec.	216 sec.	—	—
Barbey ixomit 500° F. (180 units = 30cc.)	45 sec.	51 sec.	61 sec.	60 sec.	—	—
Hot air test at 540° F. (loss)	15%	11%	2.5%	5.5%	—	—
Gas test after	Good	Good	0.5 cc.	3.5 cc.	—	—
Carbon test residue	2.51%	2.70%	4.90%	5.10%	—	—
SO_3 in residue	0.023%	0.03%	0.03%	0.04%	—	—
Loss super. steam 400°F.	0.0%	.0%	0.0%	0.0%	0.0%	32%
Loss super. steam 500°F.	5.0	4.0	1.5	1.0	5.0	67
Loss super. steam 600°F.	18.5	18.0	6.5	8.5	21.5	—
Loss super. steam 700°F.	44.0	34.0	32.5	40.5	—	—
Total loss up to 700°F.	67.5	56.5	40.5	50.0	—	—
Gas. test of oil residue from 700° test	Good	Good	1.5 cc.	3.0 cc.	—	—

"Hot Air Test: 13 grams of oil in shallow, round, flat-bottom iron dishes exposed 6 hours at 540° F. in a specially designed air bath.

"Gasoline Test: 10 cc. oil, 90 cc. petroleum ether 0.65 sp. gr. (from Pennsylvania crude) in graduated flat precipitating tubes, taking reading after 1 hour's standing.

"Carbon test using 35 grams oil according to Conradson's apparatus and method.

"Superheated Steam Test: 13 grams of oil used.

"Sample 'A' in a superheated steam test at 800° F. (427° C.) left no residue. Sample 'C' left 2.5 per cent. dry carbonaceous residue.

"Sample 'E' containing 15 per cent. of saponifiable fats subjected to the superheated steam test lost 26.5 per cent. up to 600° F.; the oil residue from this test contained 17.5 per cent. saponifiable fats. This indicates that the petroleum oil stock (B used) goes off with the steam somewhat faster in proportion to the fat oil up to 600° F. (350° C.).

"The steam pressures used in these tests were about 10 to 12 pounds per square inch. A large volume of superheated steam passed through the apparatus during the tests (about 40 cc. condensed steam per minute).

"In these superheated steam evaporating tests about 13 grams of oil were weighed into the small dish placed inside the steam vessel D. (The capacity of the small iron dish is 50 cc. having a diameter of about 48 mm. and 30 mm. high, with flat bottom.)

"The steam vessel with the oil in the dish was heated up to about 350° F. (176° C.), passing a slow current of natural gas through the apparatus, then superheated steam was admitted, the gas shut off, and the temperature raised up to the required degree and kept constant for about 75 minutes; the volatile matter in the oils at the given test temperature generally were carried over with the steam inside of 60 minutes, allowing about 15 minutes extra steaming. At the end of each given temperature test the steam and heat were shut off; after cooling, the dish containing the oil was weighed and replaced into the steam vessel and the operation repeated for the next temperature test and so on."

For a critical study of conditions to be met in superheated practice see papers by C. D. Young on "Locomotive Superheaters and their Performance" in the *J. of the Franklin Inst.*, July, 1914, pp. 1-83, and Aug., 1914, pp. 181-194, and Prof. Goss's investigations on "Superheated Steam in Locomotive Service," published by the Carnegie Institute, Washington, D. C., in 1910.

It is interesting to note that the German railways use oils of 110 to 185 Saybolt viscosity at 210° F. for saturated steam. These oils have a gravity of 18° to 28° Bé., a flash point of 540° F. or over (open cup) and contain from no fatty acids up

to 10 per cent. For superheater locomotives, oils of the following characteristics are used: Saybolt viscosity 180 to 300 at 210° F., gravity 17° to 27° Bé., flash point around 600° F. (open cup), fatty oil content 0 to 10 per cent. (Cf. Holde, Exam. of Hydrocarbon Oils, Eng. Ed., pp. 182-183). The superheaters used have higher degrees of superheat than those used in this country until comparatively recently. The crude petroleums used may be very different from the Pennsylvania oils and stocks used in this country, although much of the oil has been imported from the United States.

For actual specifications of locomotive cylinder oils see pages 174-176.

Locomotive Journals.—The journals of most locomotives are now equipped with "cellars" below the driving axle to feed grease to the journal. A large amount of grease, from 80 to 125 pounds, is required to pack an engine completely, most of it being required for the journals of the driving axles. The hard grease is packed into the removable cellar so that the cellar is filled completely and the upper part of the grease is beaten into shape to fit the axle. The cellar is then fastened below the axle. A strong spring pushes up a false bottom in the cellar and so keeps the grease pressed against the lower side of the axle. Owing to the spring pressure and the friction of the warm, moving axle, the grease wears off from the top to fit the axle.

On account of the strong spring pressure in the cellars and the great pressures on the journals, the grease must be exceedingly hard to give good results in service. It is customary to use a grease made from a heavy oil and a large percentage of soda soap, with some water and an excess of caustic. A grease containing too much water, or insufficient soaps would feed too freely to be economical in use, necessitating delays for frequent repacking. With a single packing an engine should make a large number of trips as the springs are arranged to feed most of the grease from the cellar with a little attention occasionally. Greases containing suitable solid lubricants, as graphite or mica, have been found to give good results in practice.

The pressures on locomotive journals are enormous on account of the immense weight required to secure the necessary tractive effort to move trains of 60 to 100 modern cars, some of 90 tons capacity, or a train of 1,200 tons or more. Also on account of the gauge of American railroads the journals must be made shorter than would be considered good practice for the same total pressures in other bearings. When it is considered that the pressures may amount to over 1,200 pounds per square inch, the difficulties of lubricating a large journal on a fast-moving through train, freight or passenger, with its attendant high temperatures from friction and boiler heating, are readily apparent.

To meet these abnormal conditions, the journals are well fitted with suitable bearing metal which soon adjusts itself so that the fit is perfect, making a bearing ideal for lubrication. The bearings normally work at a temperature of 130° to 150° F. as at least this much heat is required to cause the heavy grease to soften sufficiently to lubricate.

The waste grease from the locomotive journals is usually taken out before repacking the cellars. This grease is trimmed to remove any adhering grit or impurities, and is used for packing cellars on branch lines or on switch or yard engines, either directly or after heating and straining to further purify the used grease.

Many smaller engines have not been fitted with cellars for using journal grease or journal compound, and for these a suitable cylinder stock is required. Cylinder oil could be used but is not necessary as it is more expensive. A cylinder stock of 160 to 220 at 210° F. usually answers all requirements.

Crank Pins.—For lubricating the pins on driving wheels, a grease somewhat like journal grease is required, although a grease of somewhat lower soap content and a little lighter oil may be used satisfactorily. The grease is forced into a small (2-inch) cylindrical grease cup in the driving shaft, and a screw which just fits this opening is screwed in until it presses on the grease sufficiently hard to force grease into the bearing below. As the bearing warms up soon after starting, the grease begins to soften

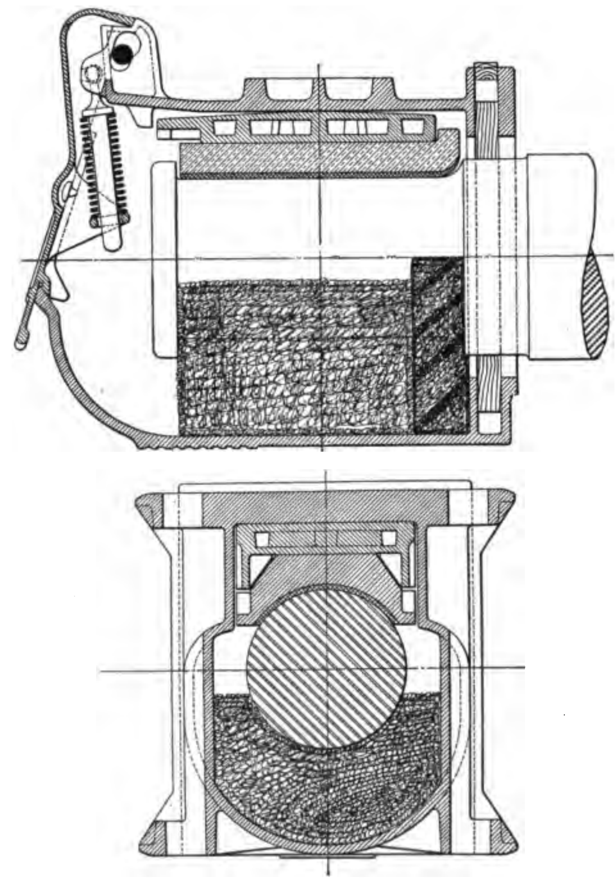
a little and lubricate the driving pins. If the grease is too soft, or of too low melting point, or if the operating conditions get too severe from any cause, the grease will all melt out. Also if the heat from the pins gets higher than 212° F. the water in the pin grease will vaporize and force out all the grease. It then becomes necessary to cool the engine somewhat, as the addition of more grease would have a similar result. Normally, as the grease is used up, the screw is given another turn, as in a compression cup, to force the grease down to the pins.

A hard grease is required as the pressures are exceedingly high, up to 3,000 pounds per square inch at starting. The lubricating conditions are favorable as the pressure is intermittent, first on one side of the pin, then on the other, so that the grease has an opportunity to get in between the rubbing surfaces.

General Engine Lubrication.—For general lubrication about the engine and tender a good engine oil of 220 to 270 viscosity at 100° F. gives good results. Some roads use regular car oil for the tender, or even for the locomotive, but the latter is hardly good practice. Systematic, frequent oiling, as is generally practiced is important. It is better to use small amounts of oil frequently than to flood the bearings at infrequent intervals.

Car Journals.—The great difficulty in the lubrication of car journals is not in getting an oil thick enough, but in getting an oil that will feed to the journal properly under the working conditions. In an ordinary bearing the pressure is on the lower side of the journal and so oil will feed by gravity to the point where it is needed. With car journals, the friction and pressure surface is on top of the axle, and the journal is equipped with a box to be packed with oil-soaked cotton waste. This waste should be frequently inspected, and loosened up or repacked, so that it presses against the moving axle, else there is no way for the oil to get to the friction surface of the journal. Many journals are cut with suitable grooves to hold some oil, but this does not take the place of careful packing and regular inspection. One journal not properly lubricated may heat sufficiently to do serious damage to the car and its content, or to delay the whole train. The

present high state of railway car lubrication has only been attained by rigid inspection of all cars before and at frequent intervals during the run. Well fitted journals are also the rule which has made possible exceedingly low lubricating costs per car mile.



Side View and End View of Car Journal Showing Packing in Place.
(By courtesy of McCord & Co., Chicago.)

In preparing waste for use in the journal boxes, it should be soaked for several days and then squeezed slightly so as not to

drip, or allowed to drain well. It is then packed into the box loosely except the part next to the inner end of the box which is well packed. The waste should come up against the lower half of the journal. The waste acts as a wick to feed the oil to the moving axle which carries it to the bearing.

Car journals are also equipped with lubricating pads instead of waste, or even with mechanical force-feed lubricators. A thinner oil can be fed with these devices.

Car Oils.—Car oils, well oils, black oils, or reduced oils, are the still residues from crudes which were originally unsuitable, or have been rendered unsuitable by the method of treatment, for use as cylinder stocks. Usually only the gasolines, kerosene and other light oils have been removed. Car oils have ordinarily never been distilled. The winter car oils are made by removing less of the lighter oils, or by cutting back the summer grade of car oil with some light distillate.

The following analyses of car oils were made by the author:

Sample No.	1.	2.	3.	4.	5.
	Summer car oil	Summer car oil	Winter car oil	Winter black oil	Black engine oil
Gravity (°Bé)	21.4	20.0	25.7	27.4	24.0
Viscosity at 210°F.	80	95	65	66	61
Flash point (°F.)	—	400	375	—	—
Sediment	—	V. dirty and tarry	Little sed.	Black sed.	Black sed.

The viscosity of winter black oil is high enough for summer use, so far as actual lubrication of the journal and bearing is concerned, but a higher viscosity oil is required in summer so as to feed properly by means of the waste. The friction loss is greater with the heavier oil than it would be with the lighter winter oil.

It has been customary to specify the viscosity of car oils at 130° F. instead of at 210° F., but the tendency is to depend more on the figures at 210° F.

The cold test of summer oil is not important, but the cold test

of winter oil should not exceed 10° F. except for southern climates. Tarry matter should not exceed 5 per cent. by the gasoline test. This includes all sediment. The gravity is not important as the cost is an important consideration and specifying gravity would probably make it necessary for some roads to go to distant fields to meet the specification. The viscosity for winter oil should be between 60 and 65 at 210° F., and for summer oil 80 to 100 at 210° F. The flash point should be above 250° F. in winter for northern climates and over 325° in summer; for southern climates the flash point might advantageously be 50° higher in each instance.

Freight cars do not stay on one road long, so it is not so much to the interest of the railway company to furnish a high-grade expensive oil. Most roads use about the same grade of oil and standard methods of packing.

Passenger coaches usually stay on the owner's lines, and are lubricated either with black oil, or oil of a somewhat better grade, or with an oil made by blending cylinder stock with black car oil.

Shop Oil.—For air-cooled compressors use a high grade cylinder stock, for water-cooled compressors use a regular air compressor oil (see Index).

For engine lubrication use a good cylinder oil of 115 to 135 viscosity as for saturated steam locomotives. Not over 10 per cent. of fatty oil is usually required.

Oil Supplies.—Most American railroads are lubricated on a car-mile and engine-mile basis. Since the railroad companies have to keep a close account of the supplies issued under these contracts, and the amounts of such supplies which can be issued are rigidly restricted, engineers are at times in real need of extra oil or grease for their engines. It is not uncommon for this to result in losses of thousands of dollars in upkeep of engines without any corresponding saving in lubricant. It ought to be to the advantage of roads not to be too strict with engineers in regard to the amount of valve oil and other lubricant issued to them. Such a condition as is often present on many railroads

would not be tolerated if the purchaser of oil supplies was the person responsible for the cost of up-keep of engines.

Oil supplies should be kept clean, both in the store-room and in the hands of the operating engineers. The custom of keeping the cylinder oil in the tallow pot warm before using in the lubricator no doubt serves to settle out anything which might choke the lubricator. Highly filtered oils are not usually required for steam cylinder lubrication.

CHAPTER X.

THE LUBRICATION OF COTTON MILLS AND OTHER TEXTILE MILLS.

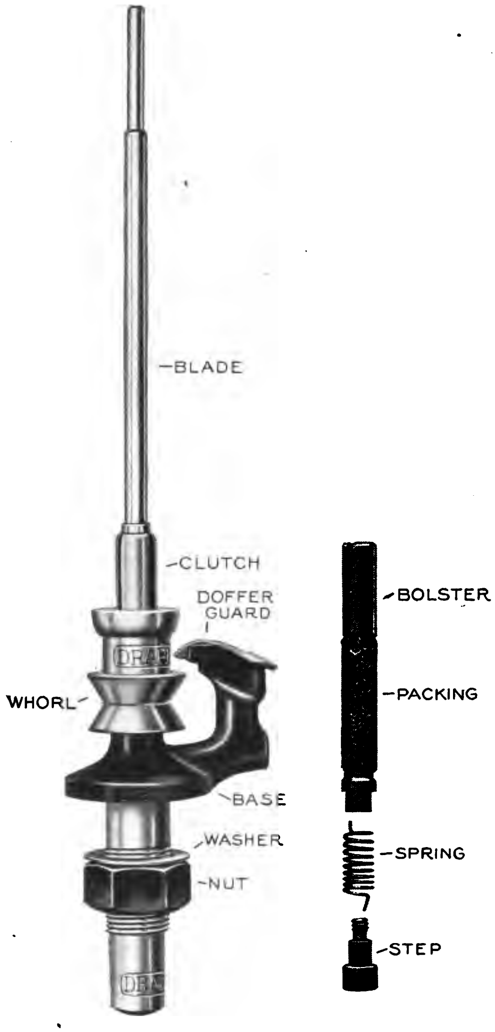
Cotton mills, in common with other plants having a large number of quick-moving machines, require the use of oils with as low viscosity as is consistent with minimum wear, otherwise the preventable power losses may be enormous.

The total cost of lubricants used in a large mill is not burdensome, but the preventable losses through the use of improperly selected lubricants may easily amount to many times the sum paid for the lubricants. A mill with 60,000 submerged spindles operated at 11,000 revolutions per minute requires 1,000 net horsepower for the spindles. A mill using spindles of the same type at 7,000 revolutions per minute requires barely half as much power for the same number of spindles. A saving in power consumption of 10 per cent., or of 20 per cent. as is sometimes possible, amounts to a considerable sum at $20.00 per horse-power-year.

The bulk of the preventable power losses in cotton mills, so far as lubrication is concerned, is connected with the more scientific lubrication of spindles, looms and shafting.

Spindle Lubrication.—An oil of just the proper viscosity is more necessary for spindles than it is for any other class of machinery. The light weight, the speed, the special design and the smooth construction of the spindle make possible the use of a very thin oil. The faster the spindle the more fluid the oil should be.

Spindles will normally run from 10° to 15° F. above the room temperature. This increased temperature does not indicate wear, for the substitution of a thinner oil would in many cases result in a temperature only 6° or 7° above room temperature, showing a power saving with the thin oil. A thicker or more viscous oil would ordinarily give a higher temperature with a correspondingly higher power consumption per spindle. The most satisfactory spindle lubrication usually accompanies the smallest tem-



A Modern Ring Spindle.
(By courtesy of the Draper Corporation, Hopedale, Mass.)

perature rise. A 5-degree reduction in the temperature of the spindle by a change of oil may be equivalent to a saving of over 10 per cent. of the power required to operate the spindle. The extra power has been consumed in stirring the oil, the lost power being turned into heat.

Spindle oils must have sufficient viscosity, or body, to keep the bearings apart under all reasonable conditions and so prevent wear; but with such high speeds less viscosity is required to keep the bearings of light spindles apart than is generally supposed.

Spindle oils are usually pure mineral oil distillates which have been rendered nearly colorless by filtering through fuller's earth or boneblack. They should be free from mineral acid and from tarry or gummy matter, and they should usually have a flash test over 300° F. in order to reduce the fire hazard. As a further indication of their safety so far as starting fires or spreading fires otherwise started is concerned, the low-flash spindle oils should not show over 4 per cent. evaporation in 8 hours at 150° F. The viscosity should be as low as is consistent with a safe flash point and with the prevention of wear.

The analyses of some typical spindle oils now used in cotton mills are given below:

	Submerged spindle oil	Light spindle oil No. 1	Light spindle oil No. 2	Regular spindle oil	Heavy spindle oil	Special heavy spindle oil (?)
Baumé gravity at 60° F.	33.8	33.0	32.6	34.1	32.6	27.0
Flash test (°F.)	275	275	285	325	345	355
Fire test (°F)	320	320	325	380	390	395
Viscosity at 70° F.	61	68	74	101	174	202
" " 100° F.	46	49	53	64	93	104
" " 120° F.	41	43	45	52	68	75

These samples gave a Maumené number of 3 or 4, showing pure mineral oils unmixed with animal or vegetable oils. The submerged spindle oil lost 3.1 per cent. in 8 hours at 150° F., and 21 per cent. in 6 hours at 210° F. It showed a loss of 1.7 per cent. in 24 hours at 70° F. The light spindle oil No. 2 showed a loss of 2.7 per cent. in 8 hours at 150° F. These figures showing evaporation loss may be taken as indicating in a gen-

eral way present day practice so far as safety is concerned, but these figures should be taken as approximating the maximum permissible loss for the conditions under which spindle oils are used. It is hardly practicable for the oil manufacturer to furnish an oil of much lower viscosity than the thinner oils given above, without at the same time lowering the flash point unduly or increasing the evaporation loss to a point inconsistent with adequate safety from a fire standpoint.

The cold test of spindle oils should not exceed 15° F., but this is a condition easily met.

The Lubrication of Special Spindles.—For the lubrication of heavy spindles, such as mule spindles or twister spindles, more viscous oils are necessary than for the lighter ring spindles. The lubrication of mule spindles would generally be done by means of such oils as the light spindle oils and the regular spindle oils shown above, but much depends on the weight and speed of the spindle, heavy spindles requiring the heavier oil and the higher speed spindles requiring the lighter oils.

Twister spindles require light or medium oils of 125 to 220 viscosity at 100° F., an oil of 150 to 175 viscosity being suitable in most cases. Such oils will usually show from 26° to 28° Bé. gravity (very expensive oils may show 31° Bé. gravity) and a flash point of 370° to 420° F.

It might be well to mention at this point, in connection with saving power through correct lubrication, that considerable excess power may be required to operate the spindle when the band pull is greater than necessary. It is as important that all bearings and moving parts be correctly fitted and adjusted as that a suitable oil be used. Spindles should be oiled regularly, every two weeks at most, and should be cleaned as often as regular inspection indicates may be required. Gummy material, if present, may be removed by rinsing with kerosene.

Stainless Oils.—The so-called "stainless oils" are alleged to be more readily removed from the fabric, or to be less objectionable than the heavier spindle oils. There are no absolutely stainless straight mineral oils as the complete removal of these oils from the fabric is impracticable, particularly if the spot is not removed

at once. The best method of removal is to treat the oil spot with olive oil or other fixed oil, let soak in and then scour with caustic soda solution or with soda ash.

The true stainless oils are altogether or largely (50 per cent. or over) animal or vegetable oils. Various mixtures of these have been used, such as sperm oil, lard oil, olive oil, cottonseed oil, neatsfoot oil, etc., alone or in mixtures. These oils are often used in lace mills or mills producing fine fabrics where the value of the manufactured product is sufficient to stand the added cost. Spots from such oils can usually be removed completely by treatment with suitable alkali solutions.

It is generally recognized as the best practice to take the necessary precautions to prevent the formation of oil spots on the cloth so that the difficulties connected with the removal of oil spots is largely obviated.

Sewing Machine Oils.—In general, the same type of neutral, paraffin or "stainless oils" are used as given for spindles. Some mills add up to 20 per cent. of sperm oil or other fixed oil to the mineral spindle oil. The viscosity generally ranges from about 50 to nearly 100 Saybolt at 100° F., the heavier oil being used for heavy sewing machines.

Loom Oils.—Owing to the character of work done by looms and the different types of looms, a large range in viscosity is necessary to meet the different requirements. The oils used are generally of the engine oil type, and range from heavy spindle oils for the light looms to heavy engine oils for the heavy looms. The viscosities range from about 100 to 225 or over. The analyses of some loom oils are as follows:

Sample No.	1	2	3	4	5	6	7	8
Baumé gravity	26.5	27.3	20.6	24.2	30.6	31.0	25.5	20.1
Flash test (°F.)	370	370	320	410	385	415	415	330
Fire test (°F.)	425	430	—	450	425	470	—	—
Viscosity at 70°F.	246	209	413	543	398	350	495	481
" " 100°F.	126	102	165	221	176	160	196	196
" " 120°F.	86	72	103	136	115	108	124	118

The oils are straight mineral oils as shown by the Maumené

test, the Maumené number ranging from 4 to 6. Oils of the type of the first four are most generally used.

Oils like No. 4 and No. 5 are suitable for looms in woolen mills, but the lighter oils are generally preferred.

Neatsfoot oil, lard oil or olive oil, either alone or compounded with mineral oils, is often used for lace machines.

The cold test of loom oils should generally be below 20° F.

General Mill Lubrication.—In order to avoid mistakes in the use of oils, the number of oils used in the mill should be reduced to a minimum. A spindle oil, a medium or heavy loom oil, a very heavy engine oil for lubricating shafting and for general heavy lubrication, a steam cylinder oil, and a turbine oil should be ample for most practical conditions. The whole scheme of lubrication should be planned so as to have oils of the proper type and proper viscosity to meet the actual conditions in the mill and then each oil should be used for lubricating in its own special field. It is of real importance that the oiling be in charge of one man whose sole or principal duty is to see that all machinery under his care is regularly and systematically oiled and cleaned as often as necessary. This is the most certain way to reduce the number of mistakes, and to save oil and machinery. By such a procedure it is not necessary to flood the bearings and so waste the oil.

Spoolers, speeders, pickers, rolls on the spinning frames, twister spindles, and miscellaneous machinery other than shafting can usually be lubricated satisfactorily with the medium or heavy loom oil used for the looms in the mill. In special cases, some of this machinery may need a heavier oil in which case the engine oil used on shafting can be used, but it is preferable to use the lighter loom oil on the faster machinery wherever practicable.

Oils used with success on the various classes of machinery have viscosities as follows:

Spoolers	180–220	Saybolt viscosity at 100° F.
Speeders	160–220	" " " "
Pickers	110–220	" " " "
Combs	160–220	" " " "
Cards	160–220	" " " "
Beaters	175–220	" " " "

Shafting Lubrication.—For shafting a very heavy engine oil is necessary. Oils with a viscosity of 220 to 290 are suitable. Generally oils from 220 to 250 can be used with satisfactory results. Oils have been used with a viscosity as low as 140 at 100° F., but this is not to be recommended.

In order to prevent constant loss of power it is necessary that all shafting be aligned properly and lubricated thoroughly. The same oil can be used for shafting and for general engine lubrication, such as bearings, slides, etc., but not for steam cylinder lubrication.

Cylinder Oils.—Cylinder oils are compounded from cylinder stocks and varying amounts of fixed oils, such as tallow oils or neatsfoot oil. The Pennsylvania stocks are preferable, cylinder oils from such stocks rarely being below 24° Bé. If oils other than Pennsylvania oils are used, the gravity should not be considered at all. The important property of a cylinder oil is the viscosity at 210° F. Light cylinder oils, for low-pressure engines, can be used with a viscosity as low as 100 at 210° F., but it is usually inadvisable to use an oil having a viscosity below 120. For high-pressure cylinders the oils should have a viscosity of 140 to 220 at 210° F. Low-pressure cylinder oils should be compounded with at least 4 per cent. of tallow oil or other fixed oil, and high-pressure cylinder oils should have 6 to 10 per cent. or more of fixed oils. When cylinders work very wet, more fatty oil is required. The flash test is always above 500° F. for Pennsylvania cylinder oils of the required viscosity.

Other uses of cylinder oils in cotton mills are for very heavy bearings, such as water wheels, on certain heavy winders and for application to overheated bearings, especially heavy engine bearings, in an emergency.

The bearings and slides of an engine can usually be lubricated with an engine oil of 160 to 220 viscosity at 100° F.

Turbine Lubrication.—For use on turbines as thin an oil as possible should be selected. Turbines normally work at 130° F. and above, so the viscosity of the oil given at 100° F. is higher than actually present under working conditions. Well-filtered,

pale Pennsylvania oils of high gravity and low viscosity are preferred as they separate from water more readily and completely. An oil which emulsifies with water is unsuitable for turbine lubrication. Satisfactory turbine oils should usually have a gravity above 30° Bé., a flash point of 400° F., and a viscosity from 125 to 160 at 100° F. Some turbines may require heavier oils, but this is seldom the case in cotton mill practice, as the engines work at high speeds. The use of turbines for cotton mills is increasing. For a further discussion of turbine oils and the emulsification test, see pages 29-31, 68-69, and 117-121.

Dynamo Oil.—Oils for dynamos and electric motors should be high-grade engine oils, preferably above 30° Bé., flash 400° F. or above, and viscosity from 120 to 200 at 100° F., depending on horse-power developed. Light electric motors, below 15 horsepower, can be lubricated with a good medium loom oil or even with a heavy spindle oil.

Lubricating Greases.—Cotton mills use greases ranging from the soft, pasty "non-fluid" oils to grease of No. 3 body.

The non-fluid oils and the very soft greases are often used for lubricating looms and cards where the tendency of an oil to splash would be undesirable. Such greases are made by compounding certain heavy metal soaps with light mineral oils. The pasty character of the oil or grease also prevents too rapid consumption and consequent waste of the lubricant. The soft "comb-box" greases are finding many uses in cotton mills, for lubricating top rolls, drawing frames, speeders, spinning frames, comb-boxes on cards, loom cams, etc.

The heavier grades of this pasty type of grease are also employed in rod cups where the copper rod serves to heat up and melt the grease so as to feed to the bearing as needed. While this cuts down the amount of lubricant consumed, a loss of power may easily result from deficient lubrication if the grease is not very easily melted. The fact that these greases are widely used indicates that they have real value in preventing undesirable oil-splashing and in reducing the amount of damaged fabrics.

The regular cup greases of No. 3 body are used on certain

heavy, closed bearings, such as for beaters and cards. All of the above greases contain light, paraffin oils. The greases containing heavy oils, similar to the greases used for heavy automobile transmission, apparently are seldom used. Graphite and mica greases find a more or less limited use for heavy work.

The Lubrication of Knitting Mills.—Ordinarily about two grades of oil are sufficient. For the small running parts a spindle oil of not over 100 viscosity is suitable. For the heavier needle plates a paraffin or neutral oil of 140 to 180 viscosity usually proves satisfactory. These two oils should usually serve for lubricating a mill operated by small electric motors, the spindle oil being suitable for lubricating small motors with ring bearings and the heavier oil (engine oil) could be used with satisfactory results on the larger electric motors.

CHAPTER XI.

THE LUBRICATION OF MISCELLANEOUS PLANTS AND MACHINES.

A. FLOUR MILLING MACHINERY.

The heavy rolls in the grinding machines revolve at high speeds and are subjected to grinding friction and grinding pressure throughout their whole length. Consequently the bearings always run warm which greatly increases the tendency to squeeze out the oil. It is, therefore, usual to lubricate the bearings of the rolls with a very heavy engine oil of 220 to 260 viscosity at 100° F. Some operators prefer to use an extra heavy mineral castor oil which seems to give ample lubrication while at the same time resisting the tendency to squeeze out of the bearings. Where rod cups have been tried the bearings seem to run hotter than where oil is used, as the increased temperature is required to make the grease flow regularly. Only soft greases should be used where the bearings are equipped with cups for grease lubrication. Generally a No. 3 grease is much too solid for this use.

The light rollers and smaller bearings are lubricated with mineral castor oil or with a light engine oil of 160 to 180 viscosity. All the rolls should be systematically oiled daily by a regular, competent oiler who is not burdened with too many other duties.

Certain small inner rollers whose bearings are in contact with the flour are lubricated perfectly without the addition of any lubricant besides the flour.

The large amount of heavy shafting requires special attention. A very heavy engine oil of 220 to 275 viscosity is required.

For the lubrication of a modern flour mill, only a very few oils are required. Besides the steam cylinder oils, there is usually needed a light engine oil of 140 to 180 viscosity for light machinery, such as fans, motors, small rolls, etc., a mineral castor oil for the grinding rolls, and a heavy engine oil of about 250 viscosity for the shafting and for general engine lubrication. On account of the large amount of dust, bearings should be inspected and cleaned regularly.

The bearings of conveyer-carriers are lubricated with a heavy engine oil of 225 to 270 viscosity.

For the lubrication of high- and low-pressure steam cylinders see Index. General engine lubrication can be had with a heavy engine oil.

In all cups where greases are to be used, whether light cup greases or heavier gear greases are employed, better lubrication can usually be had by using the softer grades of grease.

The large number of expensive belts of large size render careful attention to their condition necessary in order to prevent deterioration. By using comparatively large pulleys and oiling with suitable oils, such as vegetable castor oil, so as to keep the belts pliable and cause them to cling to the pulleys properly, satisfactory service can be had for 30 to 50 years or even longer.

B. COTTON OIL MILLS.

For all rod cups, a soft semi-grease is used. This pasty grease shows a big saving in amount of lubricant required as compared to oil, but the cost of the grease is on a somewhat higher basis than the oil. Although the bearings run warmer than with oil, the lubrication seems to be satisfactory. This grease should have a sufficiently low melting point in order to feed freely when needed. On account of the large amount of dust and lint all cups and bearings should be regularly inspected and cleaned to insure proper lubrication. Cups should be kept covered.

For general lubrication, not many oils are necessary. A heavy red engine oil of 220 to 270 viscosity at 100° F. is suitable for general lubrication of shafting, delinters, hullers, crushers and separators. In some of the heavier bearings, as on the crusher rolls, a heavy mineral castor oil would doubtless give good results over either engine oil or grease since it would not be readily squeezed out of the rolls. The bearings on the crusher are often lubricated solely by means of crude cottonseed oil.

For some of the lighter bearings, as for conveyors, etc., a medium engine oil of 160 to 180 viscosity is used.

Belts should be kept pliable by the regular use of limited amounts of vegetable castor oil or some high-grade belt oil. Ex-

cessive use of sticky belt preparations would catch an unnecessary amount of lint.

For engine lubrication, use the heavy engine oil above for the moving parts. For the cylinders, use a good cylinder oil made from a steam refined cylinder stock and 6 to 8 per cent. of acidless tallow oil. The finished oil should have a viscosity of 105 to 140 at 210° F., the lower viscosity oil being necessary for low-pressure cylinders where force-feed lubricators are not available and the higher viscosity oil being required for high-pressure cylinders.

For electric-motor lubrication see Index.

Hydraulic presses may be lubricated solely by means of crude cottonseed oil, by means of graphite or by the use of soapy water. The presence of mineral oil aids in preventing rusting of the valves. Air compressors are lubricated with a light, high-flash oil (see below).

C. ROLLING MILLS.

Hot Neck Rolls.—The conditions to be met for the successful lubrication of the large bearings or necks of rolls are enormous pressures suddenly applied, sudden stoppage and sudden reversal of the rolls, and very high temperatures of the necks due to the heating of the rolls by contact with the heated metal which is being rolled. On account of the large size of the "necks" the friction speeds are very high. The ends of the rolls are usually housed so as to protect them from dust, etc.

For the lubrication of these rolls a heavy grease of high melting point is necessary. The most generally used greases are made from heavy petroleum residuum either alone or combined with heavy tar or heavy pitches. The pitches used are mineral pitches, coal tar pitch, stearin pitch and wool pitch. The heavy tars are coal tar, pine tar, etc. The heavy petroleum oils, such as are present in good residuum, have high adhesive properties. The addition of suitable pitches or tar increases the adhesive properties of the grease. This is very necessary on account of the high temperatures and the high pressures. The adhesive properties are greatly reduced by the presence of small amounts of water in

the grease. The grease must maintain a high viscosity at temperatures of 600° or 700° F. without vaporizing or decomposing readily.

Hot neck greases are sometimes thickened with rosin, or with solid materials like talc, lime, mica and graphite. All of these greases must be melted before swabbing on the rolls, otherwise they are too heavy for easy application. Sometimes the greases are heated in a bucket and then dipped out and poured into the housing of the bearing. Used grease can be melted to free it from grit and can then be re-used.

Soap products, particularly products high in soda soaps, such as extra heavy gear greases, could be used successfully and would doubtless be used more extensively were it not for their higher cost. These greases should also be free from any water.

Cold Neck Grease.—This grease is used on the neck of rolls which are kept cool by running water. Firm greases containing soda soaps are suitable, but light tarry compounds, or pinions greases, are more often used on account of the lower cost. Sometimes heavy oils are used combined with rosin, tallow or waxes. These make greases of low melting point compared to the other greases. Suitable grades of residuum can be used without the addition of other substances.

Roll Gears.—The driving gears of rolls can be lubricated with a medium grade of light cylinder stock (105 to 140 viscosity at 210° F.) or with light residuum. The more usual practice is to use a light pinion grease, containing tar and residuum, or a dark gear grease or "dope." This is swabbed on the open gears, and should be stringy and adherent enough to cling to the gears without being squeezed off.

Cylinder Oils.—For the steam engines, unless of very high pressure, an oil of 105 to 135 viscosity at 210° F. will usually answer all purposes. Such an oil should be made from a steam refined cylinder stock free from tarry matter and should contain from 5 to 15 per cent. of tallow oil or other fixed oil. Not over 10 per cent. of fixed oil is required unless the cylinders work very wet. These low viscosity oils will generally lubricate the

yard locomotives satisfactorily. For high-pressure engines, or engines using superheated steam, oils of 140 to 180 viscosity at 210° F. should be used.

Yard Cars and Locomotives.—For cylinder oils, see above. For the locomotive journals and pins, a solid soap product containing heavy oils should be used. Ordinary grades of grease will not be satisfactory on account of the lack of resistance to the pressure springs under the journal boxes. Where the locomotives are not fitted with journal boxes for grease lubrication, a good cylinder stock of 140 to 180 viscosity at 210° F. is generally used.

The cars used in the plant and in the yard are usually lubricated with black oil or car oil. This oil should have a viscosity of over 60 at 210° F. for winter use, and a satisfactory cold test. For summer use, the oil should have a viscosity of 75 to 90 at 210° F., and should be free from excessive amounts of tarry deposit. The packing should be regularly inspected and kept in place so that the journal is actually reached by the oil. Sometimes a thin black grease or "dope" is used to lubricate the car journals.

General Lubrication.—For the lighter, faster work a good light cylinder stock of 100 to 125 viscosity at 210° F. will answer. If a cheaper oil is required, the above black car oil can be used. Various grades of thin gear greases and thin pinion greases are also available for this work.

For general engine lubrication, a heavy engine oil of 210 to 270 viscosity at 100° F. is satisfactory.

Compression cups, on cranes, etc., are usually lubricated with a medium, No. 3, cup grease.

Chain and cable greases often contain graphite, mica or talc, combined with petroleum oils and certain solidifying substances such as fats, wax, rosin, pitch, tar, and soaps.

D. MISCELLANEOUS.

Air Compressors.—On account of the great increase in temperature when air is strongly compressed, it is usual to compress in two or more stages with intermediate cooling. If no radiation or cooling took place, air taken at 60° F. and compressed under

50 pounds pressure would have a temperature of 339° F. Similarly, under 100 pounds pressure the temperature would be 485° F. and under 150 pounds the temperature would be 580° F. But as cooling always occurs the real temperatures run considerably lower.

On account of the high temperature, carbonization tends to take place as in motor oils, therefore, compressor oils should be tested for tendency to carbonize, or for sulphur which seems to influence the amount of carbonization. For safety the oil should have a flash point well above 400° F. Only straight mineral oil distillates of low cold test and high gravity (above 30° Bé.) should be used. A low viscosity oil is generally preferred, from 160 to 200 for average pressures and 200 to 250 for high pressures. A simple test for comparing these oils is the amount of darkening or deposit (insoluble in gasoline) formed on heating to the flash point for several hours. There should not be much darkening or deposit. (See Heat Test.)

If the oil is too thick it adheres to the valves where it carbonizes from the dry heat. It is important to use the minimum amount of oil and to use clean air. Low flash oils have caused a number of explosions, so the oils might very well be tested for amount of loss under heat.

Soapy water mixed with flake graphite is said to give good lubrication without causing sticking of valves, but it is necessary to feed oil just before shutting down in order to avoid rusting.

For air-cooled compressors, as on street cars and locomotives the temperatures get very high (up to 450° F. for street cars and 550° F. for electric locomotives according to Conradson). For such compressors it is necessary to use cylinder stocks, or cylinder oils.

Compressed Air Machinery.—Pneumatic tools such as drills, etc., operated by compressed air require oils of very low cold test on account of the drop in temperature of the expanding air. The cold test should be below 10° F., the gravity above 30° Bé., and the viscosity should be low as determined at 100° F.

Mine and Quarry Machinery.—For the journals of cars, summer black oil of 85 viscosity at 210° F., or winter black oil of 65

viscosity at 210° F. are generally used. The journals should be kept properly packed, should be inspected and cleaned regularly and should be protected from all gritty material as much as possible. Cheap, thin greases, called "black dope," are used to some extent for car journals.

For the lubrication of air compressors, electric motors, steam cylinders and small locomotives, see Index. Pneumatic drills and other similar tools can be lubricated with a high-grade engine oil of 180 to 260 viscosity at 100° F. The oil should have a low cold test and the wearing parts should be kept clean and free from grit.

Hoisting ropes (metal) are lubricated with coal tar containing up to 20 per cent. of lime to neutralize the tar acids. A mixture of tar and engine oil is used, alone or mixed with graphite, mica or talc. The tar aids in the exclusion of water and so prevents corrosion of the metal. Solid fats and waxes are also used with oils for the same purpose.

Ice Machinery.—For the ammonia compressors, the oil should have a low cold test (0°F.) and a flash of at least 375° F. A western oil is suitable on account of having a natural low cold test while the Pennsylvania oils require special treatment to get a satisfactory cold test. The loss on the evaporation test should be low as the carrying over of oil by the ammonia will reduce the rate of refrigeration. A high-grade spindle oil of 50 to 90 viscosity at 100° F. will give good results if it also satisfies the above condition. The gravity of western oils may be as low as 27° Bé.

For lubricating the steam cylinders, a high-grade steam refined cylinder stock should be used, either alone or compounded with not more than 2 or 3 per cent. of acidless tallow oil. A practically pure mineral oil is necessary in order to separate the condensed steam from the oil in condition for use in ice making. The emulsion of oil and water does not "break" so readily in the presence of the fatty oil. The minimum amount of oil should be fed to the steam cylinder and to the ammonia compressor.

Printing Presses.—For small and medium presses a medium to heavy red engine oil of 220 to 270 viscosity is suitable.

For heavy presses, used for newspaper work, a heavy engine oil of 300 viscosity at 100° F. is usually heavy enough for use on the cylinders. Where a heavier oil is needed a good cylinder stock of 105 to 125 viscosity at 210° F. may be used satisfactorily, but where there is any tendency to come into contact with the paper, filtered stocks are preferable to steam refined stocks. For the gears a light gear grease can be used. For lubricating electric motors, see Index.

Cutting Tools.—The office of cutting oil is to cool the cutting tool and at the same time lubricate the face of the tool. The pressure on the cutting edge is great and no lubrication is possible or desired at this point.

Mineral oils, such as kerosene oil or paraffin oils, can be used as cutting oils. They are more often compounded with 20 to 25 per cent. of fixed oil, such as lard oil or cottonseed oil, or even corn oil. Kerosene seems to work well on cast iron, but the presence of lard oil or some similar oil seems to make a cleaner, smoother and faster cut on steel and copper. The paraffin oil can be compounded with other fixed oils with similar results.

Emulsions of water, soap and mineral oils, with or without soda, are also used for cutting purposes. These so-called soluble oils are made by combining soluble soaps with light mineral oils, such as paraffin oils. The soaps may be made from fats, rosin, etc. The product emulsifies permanently, if properly made, when brought into contact with water. The emulsion is also made by dissolving a suitable soft soap in water and then stirring in a mixture of lard oil and paraffin oil. The presence of the oils and soap tends to reduce the amount of rusting which might be caused by the water. These water soluble oils are better cooling agents than the pure oil products on account of the fact that the heat absorbing capacity of water is about twice as great as that of oils.

Special merit is claimed for the suspension of graphite in water known as "aquadag.'

Where a purification system is used and the oils are available for re-use, the more expensive cutting oils can be used to advantage.

For cutting oil specifications see Index.

CHAPTER XII.

PHYSICAL METHODS OF TESTING LUBRICATING OILS.

From the large number of tests and methods available an effort has been made to give tests which meet present day requirements.

It might be well to state that no standard methods of procedure have been generally adopted. The nearest approach to standard methods is in the case of methods proposed for viscosity, specific gravity, free acid, and cloud and pour tests (cold test), recommended by a Committee of the American Society for Testing Materials (Proceedings, 1915), but these tests have not yet been officially adopted by the Society. A few methods have been proposed by the International Petroleum Commission.

A statement of the meaning or value of each test is usually given as an aid to its use and in interpreting the results obtained.

VISCOSITY.

By viscosity is meant the internal friction or "body" of an oil. In commercial instruments, the viscosity is determined by the rate of flow of the oil through a small tube, but the figures obtained are not in exact proportion to the true viscosity particularly for thin oils. Viscosity in true liquids is inversely proportional to the fluidity.

The viscosity of an oil is the most important property of the oil from a lubrication standpoint. The relation of viscosity to friction and lubrication is discussed elsewhere in this volume. The coefficient of friction has been shown to be proportional to the true (absolute) viscosity of oils at the temperature of use. The real importance of the viscosity determination has been obscured by the fact that determinations have been made at temperatures which did not represent the working temperatures, and by the fact that the viscosities as read by commercial viscosimeters do not show the true viscosity or even the exact relative viscosity, particularly for oils of less than 200 Saybolt viscosity. Thus, the real viscosity of an oil of 100 Saybolt is considerably less than half the viscosity of another oil reading 200 Saybolt. This be-

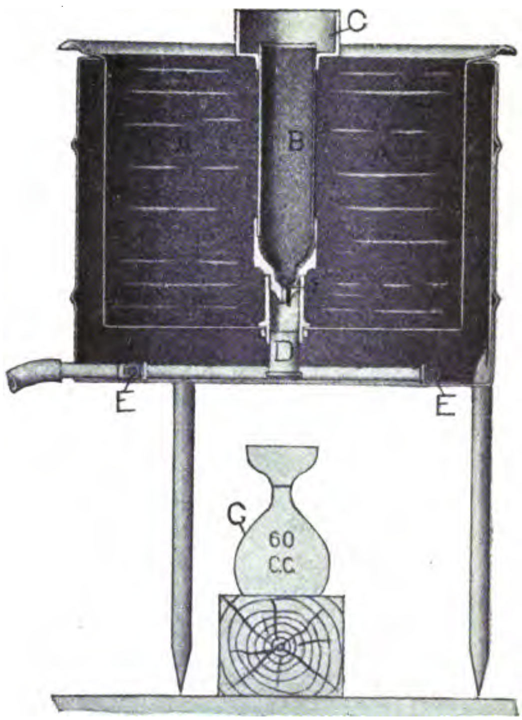
comes of greater importance when it is recalled that the viscosity as read decreases rapidly with rise of temperature and the true viscosity decreases more rapidly still than is indicated by the reading; also the temperature of the oil film actually doing the lubricating is higher than the temperature shown by any part of the bearing.

The commercial methods of taking viscosity are based on the time required for a given volume of the oil to flow through a certain size opening or tube under specified conditions. In order to make a single instrument answer for all types of oils, the opening is made too large, or the tube too short, for thin oils to register their true relative viscosities as compared to the thicker oils. The recognition of this fact will greatly extend the usefulness of the viscosity test. The Bureau of Standards has undertaken the problem of determining the absolute (true) viscosities for the Saybolt and Engler viscosimeters which should put the interpretation of viscosities on a sound scientific basis. The Universal Saybolt viscosimeter has not yet been fully standardized as to the exact dimensions of the outflow tube, so that the readings with different instruments vary more than do the readings with different Engler viscosimeters which have been fully standardized in all particulars. Ubbelohde has published tables for conversion of Engler viscosities into absolute viscosities.

The Saybolt universal viscosimeter, which is the only type of Saybolt viscosimeter now used, requires only a small amount of oil for the determination. The time of outflow of 60 cc. of oil expressed in seconds is taken as the viscosity of the oil at the temperature used. This viscosimeter requires about 28 seconds for 60 cc. of water to flow out at 68° F. (20° C.).

The Engler viscosimeter, used in Continental Europe and largely by the United States Government, requires practically 51 seconds (50 to 52 seconds) for 200 cc. of water to flow out at 20° C. (68° F.) when 240 cc. of water is used in the instrument. The viscosity of an oil is taken by using 240 cc. of the oil in the viscosimeter, adjusting the temperature to the desired point by means of the water bath which is part of the instrument, and

noting the number of seconds required for 200 cc. of the oil to flow out. The Engler viscosity or Engler number for the observed temperature is calculated by dividing the time of outflow of the oil (in seconds) by the time of outflow of water at 68° F. (in seconds).



Saybolt Universal Viscosimeter.
(Sectional View.)
(By courtesy of Platt & Washburn Refining Co., New York.)

To determine the viscosity of an oil: The water-bath (*A*) is kept at the temperature at which the viscosity is to be determined. The well-cleaned cylinder (*B*) is filled with the strained oil until it overflows into *C*. When the oil reaches the desired temperature (usually 100°, 130°, or 210° F.) the thermometer is removed from *B*, the excess oil pipetted from *C*, and the stopper (*D*) removed. The exact time in seconds noted for 60 cc. of the oil to flow into *G* is the Saybolt viscosity of the oil at the temperature used. A stop-watch should be used.

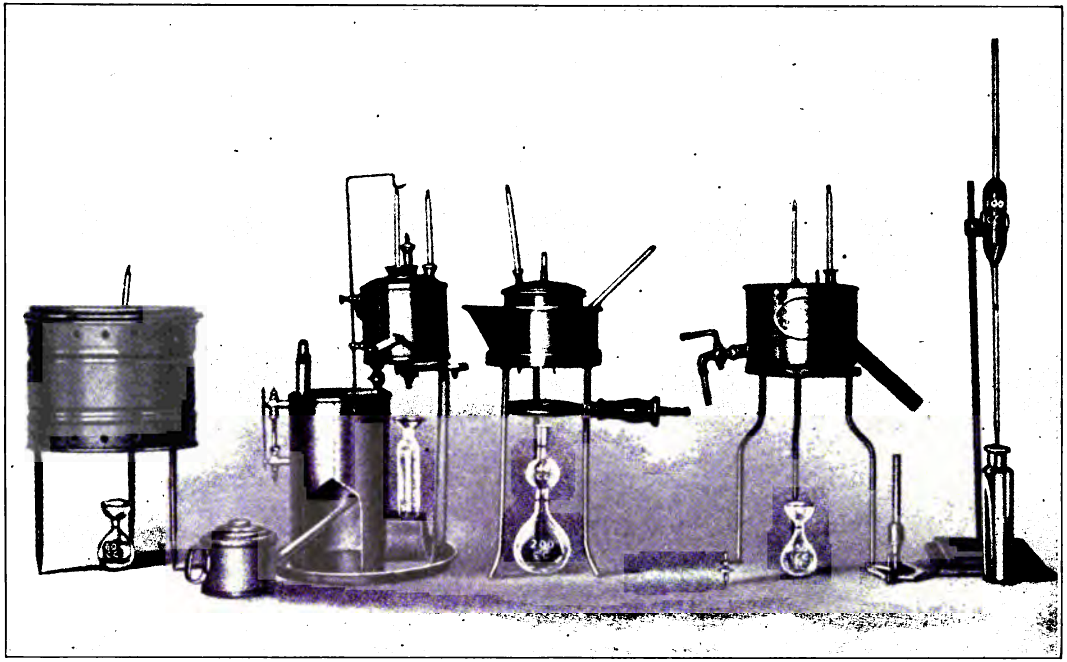
Tables are given showing the relation of Engler viscosity and Saybolt viscosity (page 218), but the relations hold only for the instruments used in making the comparisons as the Saybolt dimensions have not been fully determined as previously stated.

The Engler viscosimeter requires a large amount of oil for a complete determination, but where only a small amount of oil is available, or it is desired to shorten the time, the time of outflow of a smaller amount of oil may be taken in seconds, using a smaller amount of oil in the viscosimeter. The factors given below are used to multiply the seconds noted to find the time of outflow of 200 cc. if 240 cc. of oil had been used in the instrument. The errors are somewhat larger than for a regular determination. (See *Ch. A.*, p. 304, 1912, Offerman, also Holde and Gans.)

Amount of oil used cc.	Amount run out cc.	Multiplying factor
25	10	13.
45	20	7.25
45	25	5.55
50	20	7.3
50	40	3.62
60	50	2.79
120	100	1.65
240	100	2.35

The Dudley, or Pennsylvania Railroad pipette, is sometimes used to get comparative viscosities of oils where a standard viscosimeter is not available. An exact standardization of such an instrument is impossible, so the results are valuable only for the direct comparison of oils at room temperatures.

The old practice of taking viscosities at 70° F. is indefensible as oils are practically never used at that temperature. So long as Pennsylvania oils only were used the results at 70° F. were roughly proportional for oils of the same class at 100° F. or higher. Lubricating oils from other sources may show greater viscosities at 70° F. than Pennsylvania oils and less viscosity at 100° F. or at working temperatures, owing to more rapid thinning



Saybolt Universal | Tagliabue | Engler | Redwood | Dudley or Pennsylvania R. R. Pipette

Viscosimeters

(By courtesy of Platt & Washburn Refining Co., New York.)

The Saybolt universal viscosimeter is now used generally in the United States, superceding the older types of Saybolt viscosimeters and the Tagliabue viscosimeter which were formerly used to more or less extent. The Engler viscosimeter is used in Germany and generally in Continental Europe and has been used in the United States, notably by the Government. The Redwood viscosimeter is standard in England. The Dudley pipette is a simple instrument for comparing oils directly at ordinary temperatures.

under heat. After this preliminary thinning, the viscosities do not vary so differently upon further heating. The determination of viscosity at 100° F. has now become general in this country, except for car oils which are tested at 210° F. and sometimes at 130° F., and for cylinder oils and stocks which are tested at 210° F. The Government, following foreign practice, sometimes takes the viscosity of engine oils at 50° C. (122° F.) which seems to be good practice as this is near the possible working temperature of the oil.

The practice of taking the viscosity of engine oils and heavy motor oils at 130° F. should be encouraged, since a better basis for comparison of the true working viscosities of different types of heavy oil can be obtained at this temperature than at 100° F.

The practice of taking the viscosity of cylinder oils, as is frequently advocated, at temperatures above 212° F. is of no value for routine testing or for specifications as the viscosity at higher temperatures can be correctly inferred from the viscosity at 210° F.

The presence of soaps and other oil thickeners dissolved in an oil interfere with a correct determination of the viscosity. Such thickeners must first be removed, or the viscosity determined at a sufficiently high temperature to render their effect of minor importance, otherwise the viscosity reading will be misleading. Such oils give a "fictitious" viscosity reading.

For change of viscosity with change of temperature, see analyses under spindle oils, loom oils and cylinder oils.

Absolute Viscosities.—In commercial viscosimeters arbitrary scales have been adopted which do not give proportional viscosities for different oils even with the same instrument. This is because the outflow tube is too large and too short to register the whole energy of outflow, particularly for the thin oils. Absolute viscosities are expressed in "dynes per square centimeter" and the specific gravities of the oils are taken into account as a heavier oil will give a slightly shorter outflow time than a lighter oil of the same absolute viscosity. Corrections are also made for

the energy of flow not used in overcoming resistance within the outflow tube. The units used are not familiar to the oil trade, but will doubtless become so as soon as definite figures are published for the Saybolt viscosimeter. (See *Proc. Am. Soc. Test. Mat.*, 1915, for the work of Dr. Waidner of the Bureau of Standards; also P. C. McIlhiny, *J. Ind. & Eng. Chem.*, 8, p. 434, 1916 for tables and discussion of new units.)

It might be of interest and of value to compare briefly the Saybolt readings in terms of relative Saybolt viscosities with an oil of 200 Saybolt viscosity.

Usual Saybolt reading	True relative viscosity as compared to an oil of 200 Saybolt viscosity
400	405
200	200
100	94
76	67
50	36
40	23

The results are only approximately accurate as the effect of different gravities has not been considered and the published data is not exact, but they serve to show in a measure how the real viscosity varies more rapidly for low viscosity oils than revealed by the Saybolt readings. Thus an oil of 50 Saybolt viscosity, instead of having 50 per cent. (50/100) of the viscosity of an oil of 100 Saybolt viscosity, as might be expected, has a viscosity of 39 per cent. (36/94) of that of the 100 viscosity oil which is only 78 per cent. of the expected viscosity. This serves to indicate the need for a more rational expression of viscosity measurements or a more rational basis for interpreting viscosity.

Standardization of Viscosimeters.—For "Standard Substances for the Calibration of Viscosimeters," see Scientific Paper No. 298 of the Bureau of Standards. This paper, by Bingham and Jackson, gives exact data for the use of sugar solutions and alcohol-water mixtures. A mixture of 45 per cent. by volume of ethyl alcohol and water has a viscosity which is almost exactly four times that of water at 0° C. Since the viscosity of ethyl

alcohol-water mixtures passes through a maximum at this concentration, the viscosity does not change rapidly with the concentration, which is a marked advantage. The absolute viscosity of water at 20° C. (68° F.) is given as 1.005 centipoise.

MECHANICAL TESTS.

The usual oil testing machines give little information of value to the user of oils. The conditions of use on testing machines do not duplicate the actual service conditions, so the tests are chiefly valuable as tests of the working conditions used, or as a test of the general principles of lubrication involved, rather than a test of the suitability of the oil for a definite purpose.

Much has been learned about the science of lubrication by the use of testing machines, such as the coefficient of friction to consider as a working ideal for given pressures and speeds. Ubbelohde (Petrol. 7, p. 773, 882 and 938, 1912; see *Chem. Ab.*, p. 1986, and 2521, 1912, also p. 248, 1121, and 2678, 1913) has shown by experiment that the coefficient of friction of an oil can be calculated from the absolute viscosity of the oil (Holde, Eng. Ed., p. 125). The Saybolt and Engler viscosities are not directly proportional to the true or absolute viscosity of the oil, and this fact together with the practice of taking the viscosities of oils at unsuitable temperatures has tended to obscure the important relation between viscosity and the coefficient of friction.

High viscosity oils have high coefficients of friction and so the best oil to use in practice is an oil of just sufficient viscosity at the working temperature to keep the bearings apart with certainty under all conditions. The viscosity test, in conjunction with the available information on lubricating principles, is a sufficient guide to successful lubrication. Actual service tests can be used to confirm the accuracy of the conclusions from the viscosity determination.

Thurston and others have studied the principles underlying lubrication, and in this way the use of testing machines have proved of great service.

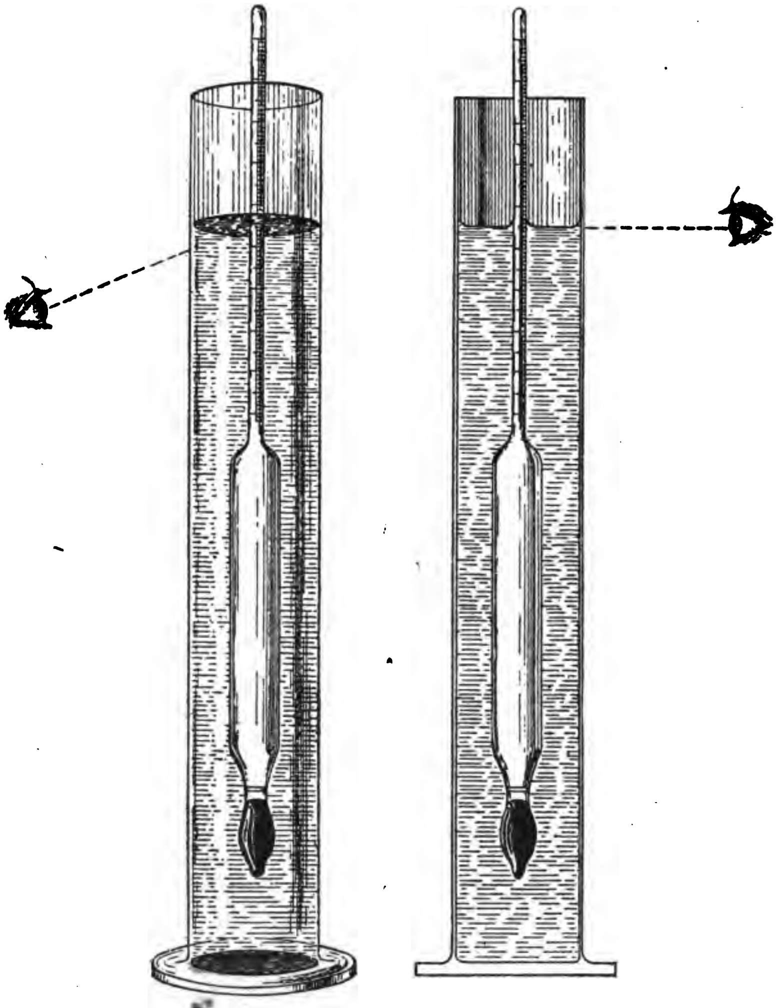
CHAPTER XIII.

PHYSICAL METHODS OF TESTING LUBRICATING OILS. (Continued.)

A. GRAVITY TESTS.

The gravity test has been accorded too much weight in judging the lubricating value of oils, consequently oils have often been found unsuitable because some more vital test, such as viscosity, has been sacrificed to meet an impracticable gravity requirement. It has great value in the refinery as a quick method of judging when to make the "cuts" or changes in distillation. So long as Pennsylvania crude was the only oil used, the gravity was an index to the viscosity and was, therefore, of real value to the user. With the production of lubricating oils from other crudes, the gravity test has lost much of its value unless taken in conjunction with other tests. The gravity is of value in judging the type of crude from which the oil was refined. Thus high viscosity oils (viscous neutrals) do not run over 30° Bé. unless from Pennsylvania or similar crude. For a given crude the viscosity is generally proportional to the gravity, but this is not necessarily true for oils of the same type from different crudes. All mineral oils contain about 85 per cent. actual carbon, so a possible variation of 1 or 2 per cent. in the carbon content of an oil as evidenced by a lower gravity can hardly be of any practical significance.

It has long been a trade custom to use the Baumé gravity (° Bé.) instead of the specific gravity. The simplest way to take the gravity is with a hydrometer as shown in the accompanying illustration. Hydrometers are made which read either Baumé gravity (degrees Baumé), or specific gravity, or both. Hydrometers can also be had in sets so that more exact readings can be made than where the whole scale is on a single spindle. Since the gravity must be taken at 60° F., or be corrected to 60° F., hydrometers may be equipped with thermometers. Sufficient time should be allowed for the thermometer to register the true temperature of the oil. For most lubricating oils the correction for



Showing Correct Method of Reading Hydrometer.
(From Bureau of Standards Circular No. 57.)

In taking the reading the eye should be placed slightly below the plane of the surface of the oil and then raised slowly until this surface becomes a straight line. The point at which this line cuts the hydrometer scale is taken as the reading of the instrument. With an oil not sufficiently clear to allow a reading as described, the reading can be made above the oil surface and a suitable correction made.

temperature is approximately 0.06° Bé. for each degree Fahrenheit above or below 60° F., the correction to be subtracted when the reading is made above 60° F. Tables are given (page 220) for correcting the gravity where the observation is not made at 60° F. (or see Bureau of Standards Circ. No. 57).

For exact determinations of gravity, the Westphal specific gravity balance, or a pycnometer (specific gravity bottle) may be used. The pycnometer should be standardized with distilled water at 60° F. (15.6° C.). The specific gravity correction is about 0.00036 for each degree Fahrenheit above or below 60° F. (equivalent to 0.00065 correction for 1° C.), the correction to be added for temperatures above 60° F. The correction is slightly higher for lubricating oils of low specific gravity. Tables are given for converting specific gravity into degrees Baumé, etc.

The Baumé scale is unscientific in that it was arbitrarily chosen and bears no obvious relation to the weight as does the specific gravity. There are a number of Baumé scales for liquids lighter than water, but the Bureau of Standards has sanctioned the scale based on the following formula:

$$\text{Sp. gr. } 60°/60° = \frac{140}{130 + \text{deg. Bé.}}$$

The specific gravity shows the weight of an oil as compared to water as unity at 60° F. Since 1 gallon of water at 60° F. weighs 8.32823 pounds, the weight of 1 gallon of oil can be calculated by multiplying this value by the specific gravity of the oil at 60° F. Heavy oils have low Baumé gravities, but high specific gravities.

B. FLASH TEST.

The flash point of an oil is the lowest temperature at which the oil gives off sufficient vapors to form an inflammable mixture with air. The flash point varies with the conditions of testing and with the apparatus used.

The flash point does not indicate the value of an oil for lubricating purposes, except in a very general way. Thus very high flash oils, such as cylinder oils, must usually have a high viscosity, and light oils such as spindle oils cannot have as high

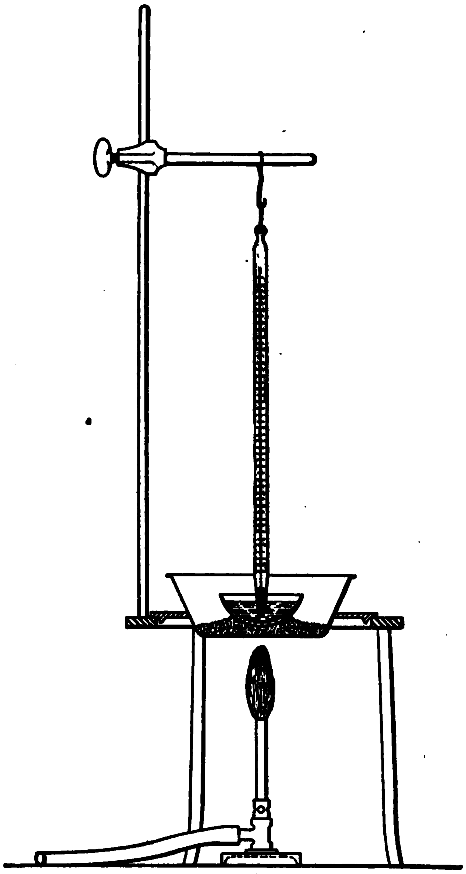
flash points as engine oils have. Also oil made from western crude may show a lower flash point than the same class of oil from Pennsylvania crude.

The chief value of the flash test is to determine the safety of an oil with respect to the fire risk and as an indication of the freedom of the oil from excessive evaporation loss during use. The fire hazard of lubricating oils is of importance where the oils are for use on fast-moving machinery, such as spindles, or for use in compressors for air, ammonia and other gases. The flash test is of special importance in connection with motor oils and other oils exposed to high temperatures. For oils not exposed to high temperatures, the flash point is usually sufficiently high, except for very low viscosity oils like spindle oils.

While many testers have been used in the United States, the best known testers for lubricating oils are the Cleveland open-cup tester, the Tagliabue open-cup tester, and the Pensky-Martens (closed-cup) tester. The flash point with the open testers may be as much as 40° F. higher than with the closed testers, such as the Pensky-Martens. The open tester has been used in the United States to the exclusion of other testers.

Similar results to those with the Cleveland open-cup tester are obtained by heating the oil in a porcelain crucible or evaporating dish, or in a glass beaker, or a sand bath (see illustration). A 50 cc. crucible or dish is suitable for the oil vessel, the oil being filled to within ¼ inch of the top only. The thermometer is adjusted so that the bulb is completely covered but does not touch the bottom of the dish. The apparatus should be protected from air currents and from the breath of the operator. The heating flame is adjusted so that the temperature rises at the rate of 10° to 12° F. per minute, and a small test flame is applied every 7° F., beginning at least 50° below the supposed flashing point of the oil. The test flame can be a small lighted splinter, or preferably a gas flame burning on a pointed glass tube, but should not be more than ¼ inch long in any case. The flame is applied by passing it slowly entirely across the dish, about ½ inch above the level of the oil and just in front of the thermometer. The flash point is the temperature read at the

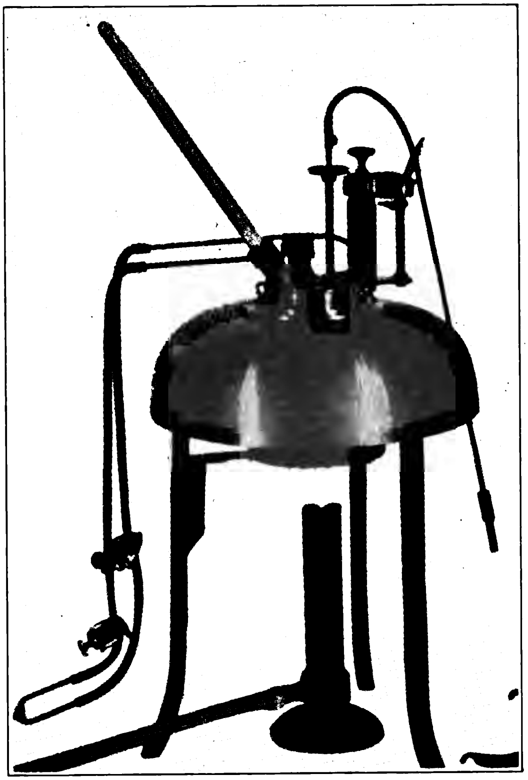
moment the vapor ignites with a slight flash. The heating may be continued, applying the flame as before, until the oil vapor continues to burn after the test flame is removed. The temperature observed is called the burning point or the fire test.



Apparatus for Determining the Flashing and Burning Points of Combustible Liquids as used by the Pennsylvania Railroad.

The porcelain dish is 2¾ inches in diameter and 1 inch deep.

The rate of heating and the method of applying the flame are very important. The results are sufficiently exact for commercial purposes.



Modified Pensky-Martens Tester, Ready for Test.
(From Tech. Paper 49, Bureau of Mines.)

This flash tester has been adopted by the National Fire Protection Association and the Independent Petroleum Marketers' Association of the United States and will doubtless be adopted by other similar organizations. This tester without the modified bath, is the official standard for testing lubricating oils in most European countries. This is the most accurate form of tester.

Thermometers are usually standardized with the bulb and stem at the same temperature, so a correction should be applied to the thermometer reading as found above. The following corrections are to be added to the thermometer reading to get the true flash point and are sufficiently exact for most purposes:

Flash-point reading (°F.)	Correction to be added (°F.)
275–300	5
300–325	6
325–350	7
350–375	8
375–400	10
400–425	11
425–450	13
450–500	16
500–550	20
550–600	23
600–650	27
650–700	30

The effect of various factors on the flash point as determined with the closed cup testers is discussed fully in Tech. Paper No. 49 of the Bureau of Mines (37-pp. with bibliography, 1914) and in a paper by the same authors, Allen and Crossfield, *J. Ind. & Eng. Chem.*, pp. 908-910, 1913. See Index for railroad methods of testing given in this volume.

C. FIRE TEST.

The fire test or burning point of an oil is the lowest temperature at which the oil gives off sufficient vapor to continue to burn after the vapor is ignited. The method of making the fire test has been given above.

Oils, particularly steam cylinder oils, have been largely sold by their fire test, which is from 40° to 50° F. above the flash test for motor oils or engine oils, and from 60° to 80° F. above the flash test for cylinder oils. The fire test has the same general significance as the flash test and gives little additional information.

D. VAPORIZATION TEST.

The amount of oil that will vaporize at any given temperature is somewhat proportional to the flash and fire tests of the oil. A low flash oil will lose weight faster than a high flash oil.

The vaporization test gives more definite information as to the extent of the loss by vaporization under definite conditions than can be inferred from the flash and fire tests. This is especially true where the oil tends to decompose under the influence of

heat. The usual procedure is to use temperatures of 212° F. or higher, up to the flash point of the oil, for a period of not more than 6 hours, the temperatures used and the time of heating being chosen with reference to the type of oil and the conditions under which the oil is to be used. Generally an air bath is used for the heating, though the heating may be conducted on a water bath for the loss at 212° F., or on an electric hot plate for losses at higher temperatures. Comparative results can be had by using the same type of dish and the same conditions for a series of tests. The form of the dish, the depth of oil in the dish and the amount of oil surface exposed greatly influence the result as does also circulation of the air to remove the vapor formed. Waters (*J. Ind. & Eng. Chem.*, pp. 394-398, 1913) recommends brass vessels 0.5 millimeter thick, 5 centimeters internal diameter and 3 centimeters high, and 5 grams of the oil.

This test is of value in determining what flash test to specify, as for spindle oils or motor oils, and for testing such oils as air-compressor oils, turbine oils, transformer oils and superheater cylinder oils. In these tests the condition of the residue, as determined by its appearance and by its behavior in the gasoline test, is of more importance than the actual loss on evaporation. (See heat test and gasoline test.)

For example of evaporation losses for various oils see Index for analyses of spindle oils, cylinder oils, railroad cylinder oils and motor oils.

E. COLD TEST.

The cold test is the lowest temperature at which the oil will still flow. Methods of making the test vary and the temperature found has many names besides the cold test, such as cloud test, pour test, flow test, chill point, freezing point, setting point, etc., etc. The oil does not solidify as a whole, but becomes solid from the freezing out of some constituent, such as paraffin.

The cold test is valuable where oils are to be exposed to low temperatures, such as on freight cars in winter, for use on pneumatic tools, etc. In general a lower cold test is required in winter than in summer. For general lubrication the cold test should be

sufficiently low to give a free flowing oil under the most severe service conditions, otherwise serious trouble may result from freezing of the oil.

The cold test has no special bearing on the lubricating value of an oil except at low temperatures. The cold test of western oils is naturally lower than the cold test of Pennsylvania oils on account of freedom from paraffin.

The usual method of making the test is to put 30 cc. (1 ounce) of the oil in a 4-ounce sample bottle fitted with a stopper carrying a thermometer, and chill the oil by immersion in a freezing mixture. The chilling is gradual and the oil is stirred during the freezing. The bottle is removed from the freezing mixture every few degrees and the temperature noted at which the oil ceases to flow in the bottle or from the thermometer bulb, this temperature being recorded as the cold test of the oil. The Pennsylvania Railroad method is to freeze the oil solid, remove the bottle from the freezing bath and note the cold test as the point at which the oil softens sufficiently to flow from one end of the bottle to the other (see Index).

The most usual method is to heat the oil to 175° F. before making the cold test.

During the determination of the cold test, the temperature may be noted at which the oil begins to become cloudy or opaque. This point is called the cloud test. It is higher than the cold test and indicates the amount of paraffin or other solid substance present in the oil.

F. COLOR AND APPEARANCE.

The color of an oil is no indication of its lubricating value. Heavy oils have deeper colors than light oils, such as the paraffin oils or non-viscous neutrals. Oils should not be darker than their viscosity warrants as such a condition is evidence of incomplete or improper refining. Highly filtered oils are paler than other oils of corresponding viscosity, but the color of oils can be lightened by acid treatment.

Red engine oils should be clear when viewed toward the light in a sample bottle. Oils should be free from any turbidity which

might indicate the presence of water, paraffin, glue or other impurities.

Cylinder oils, if free from tar, are green in color instead of black, but the gasoline test is more reliable for detecting tar.

All mineral oils show more or less "bloom" or fluorescence unless the bloom is artificially removed by the addition of nitrobenzene (oil of mirbane), or by nitro-naphthalene.

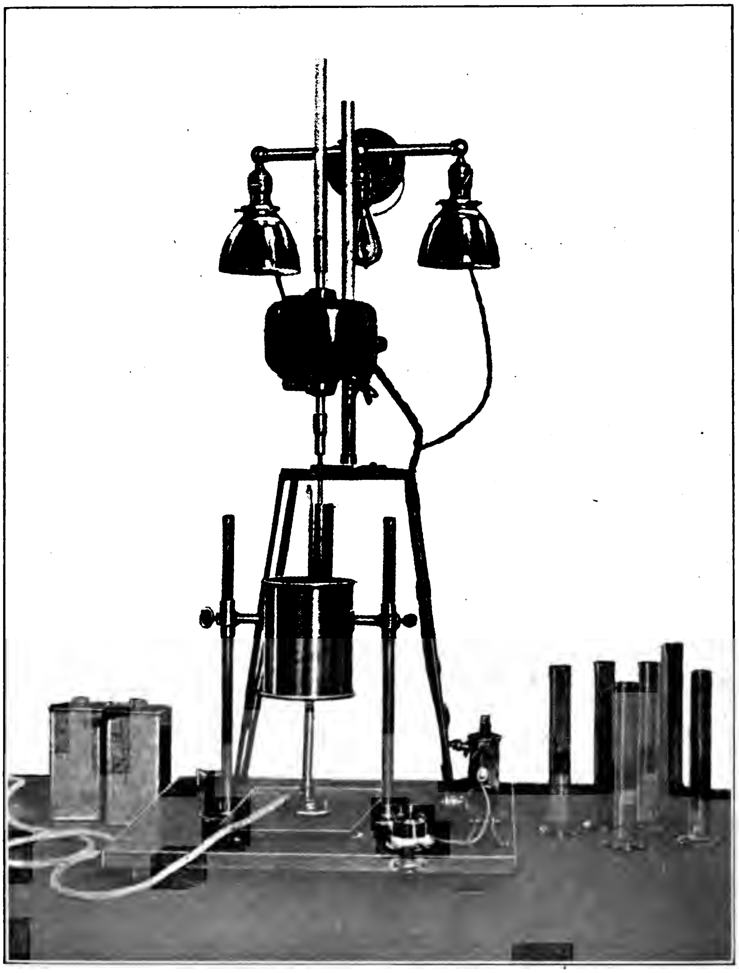
G. EMULSIFICATION TEST.

For oils used in circulating systems where the oil must be used repeatedly, such as in steam turbines, the oil must be able to separate from water readily and must retain this property during use. The tendency to emulsify seems to be related to the presence of certain sulphur compounds, soaps and fatty oils or organic acids. The most important single test for a turbine oil or similar oil, after the viscosity test, is the emulsification test. The thickening of an oil in service prevents proper circulation and lubrication, and failure to separate from water makes an early rejection of the oil necessary.

The test is made by vigorously stirring a definite quantity of the oil with a definite quantity of water. Dr. Herschel (Bureau of Standards Tech. Paper No. 86) makes the test as follows:

> "Twenty cc. of oil and 40 cc. of distilled water are placed in a 100 cc. cylinder having an inside diameter of 26 millimeters and heated in a water bath to 55° C. The liquids are then stirred with a paddle for 5 minutes at a speed of 1,500 revolutions per minute. The paddle is simply a metal plate 89 by 20 by 1.5 millimeters submerged in the liquid. The cylinder is allowed to stand for a time not exceeding 1 hour at a temperature of 55° C., and from each of the readings, taken as frequently as necessary, of the volume of oil settled out from the emulsion, there is calculated the average rate of settling between the time of stopping the paddle and the time of observation. The maximum rate of settling thus obtained is called the demulsibility, and is used as a measure of the resistance of the oil to emulsification. The maximum possible demulsibility is 1,200, as the first reading is taken 1 minute after stopping the paddle."

Small variations in the size of the paddle do not make any great difference in the result. The "demulsibility" is calculated as follows when a cylinder is used which is graduated from the



Emulsifier in use at the Bureau of Standards.
(From Bureau of Standards Tech. Paper No. 86.)

bottom up: If the reading at the upper surface of the emulsion is 50 cc. at the end of 15 minutes, the rate of settling or demulsibility $= (60 - 50) \times \frac{60}{50} = 40$ cc. per hour; for a reading of 45 cc. and a time of 10 minutes, demulsibility $= (60 - 45 \times \frac{60}{10} = 90$ cc. per hour. A high demulsibility shows a good oil. The majority of the oils on the market are either very good or very bad. Oils of high ash content show little resistance to emulsification.

The color of an oil has no real connection with the demulsibility, though highly filtered oils show high resistance to emulsification. Small amounts of impurities, too small to determine chemically, may cause an oil to emulsify, but the engineer is more concerned with the fact of emulsification than with its cause. The General Supply Committee, which makes contracts for purchasing supplies for various departments of the Government, has specified a demulsibility of 300 for turbine and spindle oils. This is approximately the value that would be obtained with a half and half mixture of kerosene and olive oil, with a volume of water equal to twice that of the kerosene and olive oil together.

Owing to the temperature and exposure to air, oils develop acid which causes the demulsibility to decrease. Dr. Herschel (pp. 34 and 35) gives the following figures for new and used oils:

DEMULSIBILITIES OF STEAM-TURBINE OILS

Section I.—New Oils

No.	Demulsibility	Comment
1	1200	Proved satisfactory.
2	192	Best satisfaction in use of any oil of this type.
3	1200 400	These two oils are in use.
	71	We have been asked to try this oil.
4	600	Proves to be very satisfactory.
5	1200	We have been using this brand for 10 years.
6	300	Satisfactory for our use.

Section II.—Used Oils.

No.	Demulsibility	Months in use	Comment
7	81	36	So far is very satisfactory.
8	85	1	Have practically no difficulty.
9	41	12	Results considered as satisfactory.
10	3	24	Contemplating a change of oil.
11	81	5	Has proven satisfactory.
12	39	12	
12	98	10	
12	87	3	
13	75	7	

Section III.—New and Used Oils of Same Brand

No.	Demulsibility		Months in use	Comment
	New	Used		
14	150	74	2	
15	280	93	12	This grade of oil has proved satisfactory.
16	600	102	24	
17	68	1	29	Oil still doing satisfactory service.
18	168	0	120	25 per cent. of fresh oil added since July, 1906.
19	1200	12	11	Discoloration due to babbitt bearings.
20	41	4	6	Deposit after 6 months' use.
21	1200	114	60	
22	94	32	10	
23	80	23	20	
24	120	102	2	Used this brand a great many years.

"If oils of sufficiently high demulsibility are used, no trouble is experienced with emulsification. It has been found also that oils of high demulsibility will last longer in use before becoming unserviceable from the formation of deposits. It seems probable that for any particular turbine in a given plant a value for the demulsibility could be found beyond which it would be unsafe to go, and that it would be an aid to the operating engineer to keep record of the demulsibility, as well as of the amount of sediment, in determining when the oil becomes unfit for use."

Phillips (*J. Soc. Chem. Ind.*, pp. 697-701, 1915) uses 500 cc. of oil and 500 cc. of water at 100° C., stirring being accomplished in a special apparatus by means of a high speed motor, the speed and time being specified. The oil-water mixture is run into graduated cylinder and the amount of separated oil

read off after 24 hours' standing. The "demulsification value" is calculated from the percentage of oil separated as compared with the amount of oil taken. He states that in actual practice with over 700 samples a demulsification value of over 90 per cent. always proved satisfactory for turbine service. This "demulsification value" is not the same as Herschel's "demulsibility." An apparatus on the same principle as the two above is used by Bryan (*J. Am. Soc. Naval Engrs.*, 26, p. 559, 1914).

Conradson's method (*J. Ind. & Eng. Chem.*, pp. 166-167, 1917, and *Proc. Am. Soc. Test. Mat.*, Vol. XVI, Pt. II, 1916) is somewhat simpler, steam being conducted from a copper retort by means of a delivery tube to the bottom of a 250 cc. graduated glass cylinder containing 20 cc. of water and 100 cc. of oil. The oil is churned up by the steam for 10 minutes. The amount and condition of the oil, the emulsion and the water are noted after standing for one hour in a water bath at 130° F.

Emulsification tests have been made by shaking oil and water together in sample bottles or in test tubes, but the results are not satisfactory as the shaking is not vigorous enough unless a special mechanical shaker is used.

Holde and Schwarz have given emulsification tests for steam cylinder oils, in which equal parts of oil and water are shaken for one minute in a wide test tube at 185° F. Not over 1 millimeter of emulsion should remain after one hour at this temperature when 10 cc. of oil are used. Unless the condensed water is to be separated from the oil after use, the chief value of the test would be as an indication of the presence of soaps which might throw doubt on the accuracy of the viscosity test. Ashing the oil would give the same information. It is not known whether an emulsification is desirable or undesirable in the actual lubrication of a steam cylinder.

CHAPTER XIV.

CHEMICAL METHODS OF TESTING LUBRICATING OILS.

Chemical methods are used to determine the nature and amount of impurities in oils, the true character of oils, and the behavior of oils under certain conditions of treatment, such as prolonged and excessive heating. Absence of chemical action and a high resistance to chemical change are desirable in lubricating oils.

A. FREE ACID.

Free acid, or acidity, is due to the presence of sulphuric acid from improper refining, to the presence of fatty acids in cylinder oils or other compounded oils, or to the development of acid in oil from exposure to heat and air. Straight mineral oil should show no acidity. Properly treated mineral oils are either neutral or slightly alkaline or show an alkaline ash. Compounded oils may develop acid by the decomposition of the fatty oils under heat.

Acids should not be present as they corrode iron, brass and other metals. Mineral acids are especially active in this particular, although fatty acids become very active and corrode metals rapidly at high temperatures. Not more than 0.2 per cent. of SO_3 or 2 per cent. of oleic acid should ever be present.

The amount of free acid is determined by putting 10 grams of the oil in an Erlenmeyer flask, adding 60 cc. of neutral alcohol, warming to 140° F. and titrating with standard alkali in the presence of phenolphthalein, the flask being repeatedly and thoroughly shaken. The acidity or "acid number" is reported as the number of milligrams of caustic potash (KOH) required to neutralize 1 gram of the oil. The standard alkali should be free from carbonates and a "blank" test should be run on the alcohol if it is not known to be neutral and the proper correction made before calculating the acidity.

To calculate the "acid number" where N/10 alkali is used, multiply the number of cubic centimeters used in the titration by 5.6 and divide the result by the number of grams of oil used. If the acidity is to be reported in per cent. of SO_3, as for mineral

acids, divide the acid number by 14. To calculate the acidity to "free oleic acid," as for compounded oils, divide the acid number by 2.

Sulphuric acid can be detected by shaking some of the oil with warm water and adding a few drops of barium chloride solution containing a little hydrochloric acid. A fine white precipitate shows the presence of sulphuric acid.

Action on Copper: Spread some of the oil on a bright strip of polished copper. The copper should not corrode or turn green after 24 hours' exposure to the air. A similar test may be made on polished steel after one or two weeks exposure.

B. ASH.

Ash is only present in appreciable quantities in oils containing soaps, either as added soaps or naphthenic soaps unremoved in the refining. Well refined engine or motor oils do not contain over 0.02 per cent. ash, and cylinder oils seldom as much as 0.1 per cent. ash which should be practically free from alkali. If the ash is red it is chiefly iron oxide from the stills.

The ash is determined by carefully burning 20 grams of the oil in a platinum or silica dish and igniting until the carbon is burned out. Final ashing may be hastened by cooling the dish, adding a little solid ammonium nitrate and reheating. A platinum dish should not be used if the presence of lead soaps is suspected.

Mineral castor oil will contain weighable ash in proportion to the amount of aluminum or other soaps present.

C. SOAPS.

Lime or aluminum soaps can be detected by shaking the oil with weak hydrochloric acid solution and evaporating the solution before making the usual qualitative tests.

Alkali soaps are indicated by a pink color when the oil is shaken with water containing phenolphthalein, also by the tendency to form emulsions with water, and to "string" or "rope" when the stopper is removed from the bottle. Alkaline soaps yield an alkaline ash which can be titrated as given under greases.

Soaps can be determined quantitatively (*a*) from the ash by titration if alkali or lime is present, (*b*) by shaking the oil with

dilute hydrochloric acid and determining the ash in the acid extract, or (c) the free acids liberated in the oil by shaking with the hydrochloric acid may be determined after thoroughly washing out all the mineral acid. This last is the better method as a very small amount of ash corresponds to a large amount of soap, particularly aluminum soaps. The free, fatty acids are not soluble in water but are soluble in oil, while the hydrochloric acid can be completely removed by shaking the oil with warm water. Emulsions formed by the warm water can be broken up by the addition of light solvents such as ether or gasoline. The acidity of the original oil as well as of the treated oil should be determined and the soap calculated from the difference between the two determinations.

D. HEAT TEST.

This test is used for oils which are to be subjected to heat, such as air compressor oils, turbine oils, motor oils, transformer oils and steam cylinder oils (for superheater). The oils are heated for six hours just below their flash points, usually 400° to 550° F., the temperature being kept at a definite point previously decided upon. The oil to be tested is put into dishes as for the Evaporation Test, or into glass sample bottles which are heated in an air-bath while air is blown through the bath. The oil is allowed to cool and any change in color is noted as well as the formation of any deposit. A very dark color with a heavy black precipitate on standing indicates much decomposition due probably to the presence of sulphur in an undesirable form. The oil is also dissolved in 88° Pennsylvania gasoline after heating and the amount of precipitate noted on standing. The best oils will dissolve clear without the formation of any sediment.

The higher temperatures (500° F. and over) are used for cylinder oils and steam may be blown through instead of air using an apparatus similar to Conradson's (see Index).

The heat test is supposed to have great value for motor oils as an indication of the amount of carbonization in practice. Studies have been made by Waters of "The Behavior of High-Boiling Oils on Heating in the Air" (*J. Ind. & Eng. Chem.*, pp. 233-237,

1911); on "The Effect of Added Fatty and Other Oils upon the Carbonization of Mineral Lubricating Oil" (*J. Ind. & Eng. Chem.*, pp. 812-816); and on the Oxidation of Automobile Cylinder Oils (*J. Ind. & Eng. Chem.*, pp. 587-592, 1916).

Waters conducts the carbonization test or heat test at 250° C. (482° F.) for two and one half hours, and filters off the precipitate formed with petroleum ether after standing over night.

E. GASOLINE TEST.

This is a test for tarry matter, asphalt, gummy material, and other impurities. These substances may be present in the original oil or formed in some of the heat tests. Usually 5 cc. of the oil are dissolved in 95 cc. of Pennsylvania gasoline (88° Bé.) by shaking and the amount of turbidity noted as well as the amount of precipitate on standing one hour or longer. No precipitate or turbidity should be noticed with the best oils.

Steam cylinder oils and stocks should be found free from tar or suspended matter by this test. The gasoline test on the oil after heating often affords valuable information as to the changes which heat will cause in the oil.

F. CARBON RESIDUE TEST.

This test, called also the carbon test, fixed carbon or coke test, is of no great value though it gives some information when used on oils which must eventually vaporize or burn, such as superheater cylinder oils, air compressor oils and motor oils. The figures obtained bear no relation to the amount of carbonization that will take place in an automobile cylinder, the heat test previously described being more closely related to actual carbon formation in practice.

The carbon residue test is made by distilling 25 cc. of oil to dryness from a special flask (Gray's), the distillation being conducted at the rate of one drop per second and the dry residue weighed.

Conradson distils 35 grams of the oil at the rate of 1 cc. per minute from a metal crucible fitted with a clamped-on lid carrying a suitable condenser. The dry residue is weighed and further analyzed for sulphur compounds. ("Apparatus and

Method for Carbon Test and Ash Residue in Petroleum Lubricating Oils," *J. Ind. & Eng. Chem.*, pp. 903-905; or *8th Int. Cong. Appl. Chem.*, I, pp. 131-132, and XXVII, p. 18.)

The carbon found in this test is formed from the cracking of heavy or non-volatile oils and indicates to some extent the stability of the oil under heat and the amount of undistilled oil present in the original oil.

G. DISTILLATION TEST.

The author has found this test of value for determining the general nature of an oil. An ordinary Engler distilling flask, about 125 cc. capacity is used, as for kerosene and gasoline distillation, using a medium sized glass tube as a dry condenser. The flask can be wrapped in asbestos cloth if desired, though a very strong flame is necessary toward the end of the distillation. The addition of as much as 12 or 15 per cent. of steam cylinder stock to a distillate can be detected by noting the temperature at which the last portion distils. Another procedure would be to distil off 90 per cent. of the oil and note the character of the residue.

H. SAPONIFIABLE FATS.

A determination of the Saponification Number, as given for Fatty Oils, is made on a 5-gram sample, using 25 cc. of the alcoholic potash solution and 25 cc. of benzol to aid solution. Since the average saponification number of most oils is 190, the per cent. of fatty oils can be calculated by dividing the saponification number by 1.9. The saponification number of mineral oils is zero.

This method is suitable for getting the per cent. of fatty oil used in compounding cylinder oils and marine engine oils. Where unblown rape oil is used for compounding, or where rosin oils are present, the results are not exact. For the detection of rosin or rosin oils, see Index.

For heavy or dark cylinder oils, 50 cc. of benzol and an extra 25 cc. of alcohol may be required to get the oil properly dissolved for complete saponification.

A working knowledge of the kind of fatty oils used in compounding cylinder oils can be gained by a comparison of the per

cent. of fatty oil found with the results by the Maumené test or by the iodine number. Also the mineral oil can be dissolved out with ether after converting the fatty oils to soaps by means of caustic potash and tests made as given under Greases.

I. MAUMENÉ NUMBER.

This is the rise in temperature (in °C.) when 10 cc. of strong sulphuric acid are run into 50 cc. of oil. (For method, see Index.) The Maumené number of mineral oils is usually from 3 to 8. The addition of fatty oil raises the Maumené number in proportion to the amount and character of such added fatty oil. The test is short and can yield considerable information, as in distinguishing cylinder stocks from compounded oils.

J. IODINE NUMBER.

The determination is made by the Hanus method on a 1-gram sample as given under Fatty Oils (see Index). The iodine number of uncracked mineral lubricating oils varies from 6 to 15. Sometimes iodine numbers of 20 are met with for pure mineral oils, the value increasing with the amount of cracking. The iodine value is increased by the addition of fatty oils in proportion to their amount and nature.

(See paper on "Iodine Number of Linseed and Petroleum Oils" by Tuttle and Smith, *J. Ind. & Eng. Chem.*, pp. 994-998, 1914, or *Tech. Paper No. 37* of the Bureau of Standards).

H. Moore (*Engineer*, 120, p. 176, 1915) considers the iodine number a good indication of possible acid formation in Diesel air compressor oils in use.

K. SULPHUR.

The amount of sulphur seems to have an important bearing on the breaking down of motor oils and the development of acidity and emulsifying properties in oils used in circulating systems, such as turbine oils.

Sulphur may be determined by burning 10 grams of the oil, absorbing the products of combustion in standardized sodium carbonate solution and titrating the excess of alkali with standard mineral acid in the presence of methyl orange. Since much of

the sulphur remains in the wick, the wick should be ashed with a little dry sodium carbonate, concentrated nitric acid and magnesium nitrate and determined gravimetrically after further oxidization in solution by means of bromine. Conradson considers the nature of the sulphur of as much importance as its amount. (See "Apparatus and Method for Determining Sulphur in Petroleum Illuminating and Lubricating Oils," *J. Ind. & Eng. Chem.*, pp. 842-844, 1912; also pp. 175-176, 1912; and *8th Int. Cong. Appl. Chem.*, I, pp. 133-136, and XXVII, pp. 19-20).

For Allen and Robertson's method for sulphur see Bureau of Mines Tech. Paper No. 26.

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CHAPTER XV.

LUBRICATING GREASES.

Greases are used for lubricating bearings where the pressures are too great for successful oil lubrication; for lubricating difficultly accessible parts of machines; for preventing undesirable splashing as in certain greases for cotton mills; for preventing waste of lubricant from poorly housed bearings; and for reducing the cost of lubrication by reducing the attention required and the amount of lubricant fed to the bearings.

Greases are made in varying consistencies, or in varying degrees of hardness, to suit different purposes, from the soft compression cup or rod cup greases to the solid greases used for locomotive journals.

The most usual type of lubricating grease to-day is the soap-thickened mineral oil type. Practically all the greases met with in general lubricating practice are made by combining mineral oils of different grades with varying amounts of lime soaps, soda soaps, or other soaps. The texture of these greases is influenced by the character of the mineral oil, the kind of soap (as soda or lime), the amount of soap, the kind of fatty oil from which the soap was made (such as tallow, etc.), by the presence of free fatty oils, by the presence of water in the grease, and by the process of manufacture.

Cup Grease.—Cup greases are nearly always lime-soap greases, from 12 to 23 per cent. of lime soaps being present combined with a mineral oil distillate of low or medium viscosity. The general practice is to use very thin oil which may not give enough lubricating body to the grease for heavy work. Water is generally present from traces up to 1 per cent. The small amount of emulsified water, usually less than 0.4 per cent., is added to give the proper consistency to the grease and to prevent ultimate separation of the lime-soap and the mineral oil. The effect of much water is to make the grease softer, so excessive amounts of water are seldom found since the addition of the water is not

economical to the manufacturer. Water also makes the grease opaque and lighter in color.

In connection with the colloidal character of greases, see paper by Holde on "The Physical Condition of Machine Greases, Oil Solutions of Lime Soaps and Heavy Mineral Oils" (*Z. angew. Chem.*, 31, pp. 2138-44; or *Chem. Abs.*, pp. 123-125, 1909).

In making cup greases it is important that only sufficient lime be used to saponify the fat or fatty oil used, otherwise the grease will contain free lime which might attack some kinds of bearings, *e. g.*, brass bearings. There should be no uncombined fatty acids in the grease, but fatty oils have only a beneficial effect on the bearings in the absence of fatty acids.

The cup greases, or lime-soap greases, are somewhat more generally used than the soda greases. Cup greases are often blended with graphite or mica. This may or may not be good practice depending on the amount and nature of such additions and the purpose for which the grease is to be used. For heavy machinery, mica and graphite are often advantageous, though the tendency is to use excessive amounts.

Soda Grease.—These greases are made by dissolving soda soaps in hot mineral oils. Heavier oils are generally used than in the cup greases, although light oils are also used. The oils used are paraffin oils, engine oils and cylinder stocks. Soda greases have a better reputation than lime-soap greases on account of the presence of heavier oils and on account of freedom from any tendency to separate into soap and oil. Where soda greases are free from water they can be melted and cooled down without separation.

The soda greases are generally known as "fiber" or "sponge" greases on account of their peculiar texture.

Gear greases or gear compounds are soda greases or sponge greases in which the soap is of a stringy character and the oil is a heavy, dark oil or cylinder stock. On account of the viscous nature of the oil these greases show good adhesive properties and a good cushioning effect.

For special purposes, some of the stiff, heavy soda greases

may contain up to 50 or even 60 per cent. of soaps for heavy bearings or journals carrying heavy loads.

Soda greases should not contain any uncombined caustic. Ordinarily, however, there is no special difficulty involved in making a neutral product.

Greases should not ordinarily be stiffer than absolutely necessary as stiff greases use up power to a marked extent.

Non-Fluid and Soap-Thickened Oils.—The non-fluid oils or solidified oils are made by combining from 0.5 to 7 per cent. of suitable soaps (lime, aluminum, lead or soda soaps, alone or mixed) with light mineral oils, such as paraffin oils. These treated oils vary in consistency from the soft pastes used for rod cups down to thick oils. Mineral castor oil is made by dissolving from 2 to 5 per cent. of aluminum soaps in a light paraffin oil, the effect being to give a stringy character to the oil and greatly increase its apparent viscosity. The real viscosity of such oils cannot be determined at low temperatures without first removing the soap.

Thickened oils and grease pastes or jellies have many advantageous applications as they can be made of fairly low melting points for use in cups where a slight increase in temperature will cause them to flow to the bearing. One of the special uses is for "comb box" grease and non-splash oils in cotton mills to prevent the lubricant from damaging the fabric.

Axle Grease.—This grade of grease is usually made from lime and rosin oil, with or without the addition of mineral oil. The lime combines with the acids in the rosin or rosin oil forming a "soap" which thickens the oil so as to form a grease. Usually more lime is used than is required to combine with the rosin acids, the excess lime remaining as a filler. Mica, talc, soapstone, and other powdered substances are also added to this grade of grease. Axle grease is only suitable for rough work, such as for use on iron bearings.

Rosin consists mainly of organic acids and is soluble in hot petroleum oils. Rosin oil, made by distilling rosin at a high temperature (above 360° C.), contains up to 40 per cent. of organic acids. The oil high in acids is most suitable for grease making.

The method of manufacture is either to stir the dry slaked lime into the cold rosin oil and let it "set" without any further stirring or agitation, or to make a cream of the slaked lime with water, this cream being stirred into the rosin oil. In this latter case the water is expelled during the rapid setting of the mix and mineral oil is then stirred in after running off the water.

Rosin greases usually contain either small amounts of water or about 20 per cent. of water.

Petroleum Grease.—Heavy petroleum residuum, after the lighter oils are distilled off to a very high temperature, is more or less solid at ordinary temperatures, has a very high fire test and a high viscosity even at elevated temperatures. It can be used directly as a hot neck, cold neck, or pinion grease, or it can be mixed with various pitches and tars for similar uses. The pinion greases are the thinner grades. These grades have high adhesive properties, particularly in the absence of water.

The thinner products containing tar, pitch, rosin and similar substances, find many applications, such as for ropes, chains, cables, gears, etc., where a cheap material is essential. They are not suitable for light fast-moving gears on account of power losses.

Petroleum grease may also be made by blending solid petrolatums, such as vaseline, with high viscosity mineral oil. Such products, whether blended with vaseline, paraffin, or tallow, have low melting points and are not to be compared with the soap-thickened greases for general uses.

ANALYSES OF GREASES.
(By the author.)

	Medium cup grease	Cup grease	No. 3 cup grease	Soft comb-box grease	Rod-cup grease	Trans-mission gear grease
Flash point (°F.)	365	345	355	360	305	540
Melting point (°C.)	83	85	83	77	—	High
Water (%)	0.4	tr.	Pres.	0	0	0
Lime soaps (%)	19.7	21.2	13.4	0	7.5	0
Soda soaps (%)	0	0	0	2.3	0	12.5
Fatty oils (%)	2.4	9.1	—	0	0	0
Gravity (°Bé.)	—	—	—	25.2	28.2	—
Gravity of oil (°Bé.)	27.7	—	—	—	31.4	25.6
Viscosity of oil (100°F)	104	—	—	—	58	High

Analyses of other greases showed from 3.2 per cent. of lime soaps for a non-fluid oil and 3.9 per cent. soda soap in a pale yellow elevator grease to 48.4 per cent. soda soap in a grease for use on laundry machinery.

COMPOSITION OF SOME GREASES.
(Gillette.)

	Flash point °C. (Open cup)	Melting point, °C.	Consistency Gms., 20 °C.	Water (%)	Calcium soap (%)	Other thickeners (%)	Mineral oil	Fatty oil	Free acid	Maximum rise in bearing temp. (°C.)	Average coefficient of friction
Graphite	195	93	18	tr.	11	16	56	17	0	53	0.097
Summer motor	160	87	170	tr.	38	—	36	25	tr.	39	0.075
Winter motor	175	86	7	tr.	23	—	40	37[5]	6.1	42	0.063
K_1	193	85	24	0.2	16	—	67	16	0	38	0.057
K_2	195	93	66	0.3	20	—	60	20	0.3	39	0.054
Auto	190	79	11	1.0	19	—	60	20	tr.	32	0.046
Tallow A	210	52	(150)	2.5	—	1.4[1]	22	73	0	22	0.022
Tallow XX	215	49	200	tr.	30[7]	2.1[1]	20	48	0	25	0.029
Lead rosin oil	240	102	7	24.7	—	1.7[2]	—	0	0	40	0.067
Lime rosin oil	198	77	31	tr.	—	9.9[3]	—	0	0	42	0.048
Lime rosin oil	198	75	4	20.0	—	7.8[3]	—	0	0	29	0.036
Soda grease	215	83	35	0	—	22.[4]	78[6]	0	0	17	0.019
Non-fluid oil	210	76	27	0	9.8	12.9[4]	70	7	0	25	0.026
No.4 petrolatum	247	47	6	0	—	—	100	0	0	16	0.018
Lard oil	265	5	0	0	—	—	0	100	—	7	0.011

[1] Potash soap. [2] Lead (soap). [3] CaO. [4] Soda soap. [5] Mainly palm oil. [6] Oil of 24.2°Bé. [7] Paraffin.

Gillette ("Analysis and Friction Tests of Lubricating Greases," *J. Ind. & Eng. Chem.*, pp. 351-360, 1909), classifies commercial greases as follows:

"A. The tallow type: These greases are made up of tallow and more or less of an alkali soap, commonly the sodium or potassium soaps of palm oil, mixed with a smaller amount of mineral oil. These were the principal types of lubricating grease ten or twenty years ago, but to-day are less used than the greases of type B.

"B. The soap-thickened mineral oil type: These are the most common journal greases to-day, and are composed of mineral oil of various grades made solid by the addition of calcium or sodium soaps. Calcium soap is more used than sodium.

"C. Types A or B with the addition of a mineral lubricant—usually graphite, mica, or talc.

"D. The rosin-oil type: These consist of rosin oil thickened by lime, or less commonly, litharge, to which is added more or less mineral oil, either paraffin or asphalt oils being used. These are sticky, usually contain 20-30 per cent. of water, and find their chief application as gear greases where true lubrication is not so essential as prevention of wearing and rattling of the gears. Some very heavy bearings are occasionally lubricated with this type of grease. Tar, pitch, graphite and such fillers as wood pulp and ground cork are often put into these gear greases.

"E. Non-fluid oils: These are thin greases stiffened to some extent with aluminum oleate or a mixture of soaps, as sodium and calcium.

"F. Special greases, such as mixtures of wood pulp and graphite, thin greases of any of the above types mixed with wool or cotton fibers, hot-neck greases, freak greases containing rubber, etc.

"Of these A, B and C are the most important as lubricants.

"The analysis of a lubricating grease may have one of two objects in view: to duplicate the grease, or to determine its value as a lubricant. Without resorting to mechanical tests of the actual friction reducing power of the grease in question, the first is probably the easier problem."

Gillette gives the analysis of a number of greases (see above) and the friction tests on a small Thurston testing machine fitted with a compression grease cup. In connection with these tests which were made at a pressure of 60 pounds per square inch of projected bearing area and a speed of 310-320 revolutions per minute, he makes the following statements:

"The general behavior of a grease during the run (3 hours) was as follows: At first the coefficient of friction would be high, and the temperature would rise rapidly. In the case of a hard grease, as a rule, this would continue until the thermometer showed some certain temperature, nearly up to the melting point of the grease. The surface of the bearing probably did reach that temperature, although the thermometer did not register quite that temperature, as there was some chance for radiation.

"After the grease had apparently melted, and the bearing was then in the state of an oil-lubricated bearing, the coefficient of friction would momentarily fall off, sometimes to a very low figure, and the temperature would drop rapidly. Then the grease would seem to stiffen again, and the coefficient and temperature would immediately rise again. The graphite grease shows this behavior to the greatest extent. This would go on for perhaps an hour, when a condition of equilibrium would be established, and a fairly constant reading would be attained.

"Since the friction cannot be reduced till the temperature of the bearing has risen enough for the grease to melt, or at least to be softened so it can flow over the bearing, it follows that other things being equal, the grease with the highest melting point will produce the highest coeffi-

cient of friction. Hence the lowest melting grease that will stay on the bearing will have the lowest coefficient of friction, which is only another way of saying that a grease already melted, *i. e.,* an oil, will give the best results wherever it can possibly be used.

"There is no direct proportionality between the results of the determination of any one analytical constant and the lubricating power, though there seems to be an approximate relation between the melting point and the friction reducing power, as would be expected. The relation, however, is not close enough to allow us to predict the lubricating value from the melting point without taking the chemical composition and the physical constants into consideration.

"The graphite grease showed an unexpectedly low lubricating power, and would be best fitted for a gear grease. The rosin oil greases, which are usually considered to be very poor lubricants, showed high friction at first, but after the bearing had warmed up enough to soften them somewhat, they compared well with the more expensive greases. The high moisture content of most of these greases would seem to be no drawback, but rather an advantage in rendering them less sticky.

"It will be noted that the lime soap greases, the most common type to-day, do not give as good results as the older, though more expensive tallow greases. It will also be seen that the greases compounded with soda soaps are better lubricants than those compounded with lime soaps."

In connection with the above tests, it might be well to caution the reader against drawing too sweeping conclusions, either for or against any one of the greases mentioned, when used under radically different conditions of pressure and friction speed than those used in the tests.

CHAPTER XVI.

METHODS FOR TESTING AND ANALYSIS OF GREASES.

On account of the great variety of greases much must be left to the judgment and ingenuity of the analyst. Reference should be made to the chapters on Methods of Testing Lubricating Oils and Animal and Vegetable Oils for the identification of oils extracted from the grease. The kind of fatty oil used in making up the grease can be determined with reasonable certainty where only one kind of fatty oil has been used. If a mixture of fatty oils has been used the identification is much more difficult and less certain.

Preliminary Examination.—Much may be learned by noting the color of the grease, and by noting its odor particularly during the determination of the flash point. The presence of tallow, of rosin and rosin oil and of certain other oils may often be detected by the odor of the warm grease. Greases made from low grade fats or tar oil often have some scenting material added, such as oil of mirbane (nitro-benzol). Very pale greases ordinarily contain thin oils, such as low viscosity paraffin oils. If the grease is completely soluble in ether or gasoline, no soaps are present, and water would be shown by a turbidity of the solution if present in appreciable quantities. The presence of soap can also be detected easily by burning a little of the grease on a platinum crucible lid, or in a crucible. If any ash is present soap is indicated and the kind of soap (lime or soda, etc.) can be found by testing in a flame on a platinum wire with hydrochloric acid.

The taste of grease is often characteristic, but misleading tastes may develop on the surface exposed to air and light.

PHYSICAL TESTS.

The chief physical tests are determination of the melting point, flash point, consistency, and the water content.

Melting Point.—This is the most important single determination, particularly for all kinds of cup greases. The melting point is chiefly dependent on the amount of soap present, the kind of

soap (lime or soda, etc.), the kind of fat from which the soap was made, the nature of the mineral oil used (if very heavy), and the amount of water present and its condition. Greases of high melting point show high coefficients of friction on testing machines and in service.

Gillette uses the following method: A piece of open glass tubing 8 centimeters long and about 0.4 centimeter internal diameter is stuck into the grease so that a plug of grease 1 centimeter long is left in the glass tube. The tube is then attached by a rubber band to a thermometer so that the grease plug is even with the bulb. The thermometer with the tube attached is then immersed in a beaker of water so that the bottom of the plug is 5 centimeters below the surface. The water is then heated at the rate of 3°-4° C. per minute. When the melting point is reached, the plug, which is under a pressure of 5 centimeters of water, slides upward in the tube. Checks can be obtained to 0.5° C., and slight variations in diameter of tube, depth of immersion, length of plug, and rate of heating would rarely cause more than 1° variation from that obtained by the prescribed procedure.

The melting point can also be determined by putting the grease in a capillary tube closed at one end and noting the temperature at which the grease becomes transparent when heated in a water bath. If the grease is melted in order to get it into the tube the melting point determination should not be made for several hours, as a freshly melted grease would give a different result from the original grease. The so-called dropping point can be determined roughly by smearing some of the grease on the bulb of a thermometer and heating the thermometer in an air bath. The reading can be taken when the grease runs down to the end of the bulb or when it actually drops from the bulb. The amount of grease used causes variation in the temperature reading.

Greases do not melt sharply as a rule, so that the temperature at which they soften sufficiently to flow under a suitable small pressure seems the most logical and definite point to designate as the melting point.

Often much information of value may be obtained by putting some of the grease on a wire gauze and holding high over a gas

flame. The melting point is roughly indicated, and any tendency for the grease to separate will be shown by the oil running through the gauze leaving most of the soap behind.

Flash Point.—The flash point can be taken with any good open-cup tester, or by putting the grease in a 50 cc. porcelain crucible which is placed in a sand bath and heated at the rate of 5° C. per minute, a small testing flame being applied every 3° C.

The flash point gives an idea of the grade of mineral oil used without going to the trouble of actually extracting the oil. Ordinarily the thin oils have correspondingly low flash points.

Consistency.—This property of a grease or fat is determined by using a special apparatus which is essentially a pointed rod of a certain weight and shape, and noting the weight required to cause the rod to sink 1 centimeter into the grease at 20° C. (68° F.). Sometimes the reading is obtained by taking the time required for the rod to sink a certain distance into the grease under a definite weight. This test has no special bearing on the lubricating value of the grease, but has importance in connection with the use of the grease in compression cups, etc.

Water.—The water content of greases is important and necessary in order to give them the proper texture. This is particularly true for lime-soap greases, but only very small amounts of water are necessary if properly emulsified. The moisture can be determined by heating in an air bath at 110° C. until all frothing ceases. On account of the presence of volatile hydrocarbon oils, this method gives from 0.5 to 2 per cent. too high, depending on the character of the mineral oil and the amount of moisture present. The heating should be as brief as possible.

Where very exact work is required, Gillette (*J. Ind. & Eng. Chem.*, p. 356, 1909), recommends Marcusson's xylol method: The grease is first tested with anhydrous copper sulphate if the grease is sufficiently light in color. If the copper sulphate turns blue showing the presence of water, or if the grease is dark, 10 grams of the grease are weighed into a 300 cc. Erlenmeyer flask and covered with xylol. (This xylol is prepared for use by distilling from water and separating out from the water after clear-

ing in a separatory funnel.) The flask, connected with a dry condenser, is heated in a bath of cylinder oil, and the xylol and water slowly distilled off until the xylol comes over clear. The bulk of the water comes over with the first 10 cc. of distillate. The distillate may be caught in centrifuge tubes, or other suitable tubes, and the amount of water read off after centrifuging or on standing.

CHEMICAL TESTS.

The chief chemical determinations are: the amount and nature of the oils, the amount and nature of the soap, the amount of free acid or alkali, ash and filler.

The Oils.—The oils can be removed by extraction with ether or gasoline in a Soxhlet extractor. The oils are then recovered by driving off the solvent from the dissolved oil. If lime soaps are present some of the soap is also dissolved so the separation is not satisfactory. In this case the nature of the oil can be determined after extraction of the grease with cold ethyl acetate which seems to be about the only organic solvent which can be used at all successfully.

The proportion of fatty oil can be determined by saponification with alcoholic potash and benzol as given for the determination of fatty oils in cylinder oil (see Index). The fatty acids from this saponification can be recovered if desired and tested for further identification by the iodine number, melting point, etc. The per cent. of fatty oil in the mixed oils can be calculated from the saponification number by dividing by 190 and multiplying by 100. The average saponification of most fatty oils, except rape oil, rosin oil, etc., is about 190.

Rosin oil is tested for by means of the Liebermann-Storch reaction, and the amount of rosin acids can be determined by Twitchell's method if desired.

Soaps.—A satisfactory scheme for determining the amount of oils and soaps is as follows: Stir 10 grams of the grease with ether until dissolved or disintegrated, place the whole in a separatory funnel and shake with about 10 cc. of 1 : 1 hydrochloric acid to decompose the soaps. Remove the acid and shake the ether

with another 10 cc. portion of the acid. Continue to wash the ether with successive small portions of water until all the acid has been removed. The ether now contains all the mineral oil, all the fatty oils, the original free fatty acids, and the fatty acids obtained from decomposing the soaps. The acid solutions and washings contain the bases in solution. The extraction can be made with naphtha, petroleum ether or very light gasoline instead of with ether.

The oils can be recovered by driving off the ether and weighing. The fatty acids are determined by the method given below for acidity, and the free fatty acids present in the original grease deducted; the remainder is the fatty acids from the decomposed soaps. The soaps may be caculated by multiplying the per cent. of such fatty acids by the following factors: Soda soaps 1.078, calcium or lime soaps 1.067, lead soaps 1.364, and aluminum soaps 1.032. If the grease contained more than one base, as in a mixture of soda and lime soap grease, the soap can be calculated to sufficient accuracy for ordinary purposes. The calculations are reasonably exact if rosin acids are absent.

The acid extract is evaporated, with or without washing with ether, the residue dissolved in water and analyzed for the bases present. These figures, if obtained, would serve as a check on the results calculated above.

Another method for determining the amount of soaps, where only alkali soaps are present, is by extracting the grease with ether or gasoline as given under "The Oils" just above, and then extracting the undissolved residue with hot water or hot alcohol. After filtering, the solution is evaporated to recover the soap which is weighed. The nature of the fatty acids can be determined by dissolving the soaps in water, liberating the acids by means of mineral acid, warming on a water bath until the acids separate clear on top of the water layer, and testing the acids for iodine number, melting point, etc.

The easiest method for determining the amount of soap is to ash several grams of the grease, dissolve the ash in standard (N/2) acid and titrate the excess of acid with standard alkali using methyl orange as indicator. Each cubic centimeter of N/2

acid is equivalent to 0.1535 gram of sodium stearate or 0.1520 gram of calcium stearate. This is sufficiently accurate unless rosin soaps are present in which case the result will be slightly low. The nature of the base in the soap can be found by inspecting or testing the ash, or by analyzing the acid solution for lime or aluminum.

Free Acid.—The amount of free acid can be determined by dissolving 2.82 grams of the grease in a neutral mixture of alcohol and ether, adding a few drops of phenolphthalein solution and titrating with N/10 alkali. Each cubic centimeter of the alkali is equal to 1 per cent. of oleic acid. The free acid should be below 2 per cent. as any free acid might corrode the bearings. Only fatty acids are present in the free state in soap-thickened greases. If the alcohol-ether solution turns pink upon adding the phenolphthalein, free alkali, usually lime, is present.

Ash.—The ash contains the alkalies (Na_2CO_3, CaO, etc.) and mineral impurities. The amount of the latter should be small or well under 1 per cent. By analysis of the ash the character and the amount of soaps can be determined, as lime, soda, potash, lead, zinc, magnesium, alumina, etc.

Filler.—If graphite is present the approximate amount can generally be determined by ashing the grease at a low temperature, weighing, then burning completely and re-weighing. This loss in weight can be reported as graphite, although graphite usually contains from 10 to 20 per cent. ash. Complete separation by extraction is not always practicable if graphite is present.

Mineral fillers can be determined by the ash after deducting the alkalies found, or by actually weighing the ash not dissolved by acid. These methods are suitable for determining the amount of mica, talc or soapstone, but not for determining the amount of lime filler as this would be dissolved by the acid.

For soda greases the amount of filler can be determined by extracting the grease with ether, then with alcohol, the final residue being the filler provided the extraction was complete and the filtrates clear.

CHAPTER XVII.

ANIMAL AND VEGETABLE OILS.

Oils and fats are found ready formed in all animals and in the seeds of plants. A fat is simply an oil which is solid at ordinary temperatures. Animal and vegetable oils are called fatty oils, fixed oils, or saponifiable oils.

Chemically, fatty oils are made up almost entirely of heavy fatty acids in combination with glycerine. Sperm oil which is a liquid wax rather than an oil has the fatty acids combined with other alcohols instead of with glycerine. However, most oils yield about 10 per cent. of glycerine when acted on by caustic potash.

The formula for glycerine is $C_3H_5(OH)_3$.

The three most widely distributed fatty acids are

Stearic acid, $HC_{18}H_{35}O_2$,
Palmitic acid, $HC_{16}H_{31}O_2$, and
Oleic acid, $HC_{18}H_{33}O_2$.

There are many other fatty acids, some of which are important. They usually have smaller molecules than stearic acid (like butyric acid, $HC_4H_9O_2$, found in butter), or they have less hydrogen than oleic acid (like linolenic acid, $HC_{18}H_{29}O_2$, found in linseed oil).

The fatty acids are not present in the oil in the free state to any great extent, but are combined with the glycerine. The glyceride of stearic acid, which is the compound actually existing in many fats, is called stearin which has the composition

$$C_3H_5(C_{18}H_{35}O_2)_3.$$

In general, glycerine holds in combination 3 molecules of stearic or other fatty acids. Stearin, palmitin, $C_3H_5(C_{16}H_{31}O_2)_3$, olein, $C_3H_5(C_{18}H_{33}O_2)_3$, and similar compounds make up practically all of the animal and vegetable oils and fats.

All *fats* contain a large percentage of stearin or palmitin as well as some olein. All oils contain considerable amounts of olein, or similar compounds with relatively less hydrogen than is present in stearin.

When any fatty oil is treated with caustic soda or caustic potash the oil is broken up by the caustic into glycerine and *soap*. Soap is the compound formed between the soda or potash and the fatty acids. This breaking up of the oil into glycerine and soap is called *saponification*. Thus palmitin is acted on as follows:

$$\underset{\text{Palmitin}}{C_3H_5(C_{16}H_{31}O_2)_3} + \underset{\text{Caustic Soda}}{3NaOH} = \underset{\text{Glycerine}}{C_3H_5(OH)_3} + \underset{\text{Soap}}{3NaC_{16}H_{31}O_2}.$$

All fatty oils are saponified by caustic alkalies while mineral oils cannot be saponified. During the saponification of an oil a definite amount of caustic is used up.

Another striking characteristic of oils is the amount of iodine each oil can absorb or combine with directly. Oils like linseed oil, which are known as drying oils on account of their power of thickening upon absorbing oxygen, have high iodine absorbing power. Other oils, which dry only slowly and incompletely, like cottonseed oil, are called semi-drying oils. These have somewhat lower iodine values. Finally, the non-drying oils have still lower iodine values. The non-drying oils show very little tendency to gum or thicken when exposed to the air.

The drying or non-drying character of an oil is determined by the relative amount of hydrogen present in the fatty acids making up the oil. The less hydrogen the oil contains, the more readily it dries and the more iodine it will absorb. Fatty acids, like stearic and palmitic acids, which have the general formula $C_nH_{2n}O_2$, do not combine directly with iodine and so are called *saturated* fatty acids. Consequently the corresponding compounds, stearin and palmitin, do not have the power of combining with iodine.

Unsaturated fatty acids combine with a definite amount of iodine. Oleic acid and other acids with the formula $C_nH_{2n-2}O_2$, can combine with 2 atoms of iodine. Linolic acid, found in cottonseed oil, and other acids with the formula $C_nH_{2n-4}O_3$, can combine with 4 atoms of iodine. Linolenic acid in linseed oil has the formula $C_nH_{2n-6}O_2$ and so can combine with 6 atoms of iodine.

Usually semi-drying oils have a large percentage of combined fatty acids capable of absorbing 4 atoms of iodine, while drying oils have much fatty acids which can absorb 6 atoms of iodine.

A large proportion of saturated fatty acids, with a fairly low iodine value, is characteristic of *fats,* while the *oils* contain a greater proportion of unsaturated acids with a higher iodine value. Vegetable oils are usually, though not always, more highly unsaturated than terrestial animal oils.

Within the last few years a process, known as "hydrogenation" or hardening of oils, has been devised to change unsaturated oils into saturated oils or fats on a commercial scale. This process which makes a fat out of an oil depends on the use of nickel which acts "catalytically" to cause hydrogen gas to combine with the heated oil. Thus olein can be converted into stearin. *Solid edible fats* can be made in this way from cottonseed oil, from fish oils and many other oils.

Many oils when first extracted are brown in color and have undesirable odors. The oil can be refined by treatment with sulphuric acid and caustic soda, or by filtration through fuller's earth, or by agitation with steam and air, so that the resulting oil is only slightly colored. The caustic soda treatment removes the small amount of free fatty acids which is often present in crude or rancid oils. Refining also improves the odor and keeping qualities of the oil.

VEGETABLE OILS.

Many of the vegetable oils are semi-drying or drying oils. Only the non-drying oils are satisfactory for lubricants as the other oils tend to gum or thicken. The chief vegetable oils used in lubrication are rape oil, castor oil and olive oil.

Castor Oil.—This pale green oil is extracted from the seed of the castor oil plant. It has a higher viscosity and holds its viscosity better under heat than any other fatty oil. It has the highest specific gravity of any of the usual fatty oils, but blown oils and rosin oils may have as high specific gravity. It consists largely of the glyceride of ricinoleic acid which differs from most fatty acids in having an extra oxygen atom. Castor oil unites

readily with sulphuric acid to form soluble castor oil or Turkey red oil. The saponification number is low. The poorer grades have a nauseous odor and taste. Commercial castor oil contains from 1 to 14 per cent. of free fatty acids. Not over 3 per cent. should be present.

Castor oil is the only important oil readily soluble in cold alcohol. The presence of less than 10 per cent. of other oils in castor oil can be detected by shaking one volume of oil with five volumes of ordinary 95 per cent. alcohol at room temperature, failure to form a clear solution shows the presence of other oils.

Castor oil has been widely used for lubricating heavy, quick-moving machinery, but the high price of this oil and the introduction of suitable heavy mineral oils has largely supplanted its use for this purpose. Castor oil is often used for compounding with mineral oils, but trouble often results from failure of the castor oil to remain in solution in the mineral oil. Separation of the castor oil from the mineral oil can be prevented by using some other fixed oil along with the castor oil.

Corn Oil (Maize Oil).—This is an important semi-drying oil which may at times find its way into lubricants, particularly by addition to lard oil and other oils. Such addition is undesirable.

Cottonseed Oil.—This is an important semi-drying oil. It is not much used for lubrication on account of its gumming tendency, but it has been unwisely recommended for use in compounding cylinder oils. It is often used to adulterate other oils. Its presence can be detected by the Halphen test or by the Bechi test. (See Index.)

Linseed Oil.—This is the most important of the drying oils. It is not used in lubrication, but finds its chief uses in paints, varnishes and soaps. Its drying properties are increased by boiling the oil with lead or manganese oxides previous to use in paints and varnishes. This "boiled oil" has a higher specific gravity and a lower iodine number than the raw oil. The raw oil has a higher specific gravity and a higher iodine number than any oil that is likely to be used to adulterate it. The chief adulterants are cottonseed oil, corn oil, soy-bean oil, fish oils and rosin oils.

Olive Oil.—This non-drying oil is pressed from the pulp of the olive fruit. The poorer qualities only are used for lubrication as the better grades are too expensive. The oil is greenish in color and may have from 2 per cent. to 25 per cent. of free fatty acids. Olive oil for lubrication should have less than 4 per cent. of free fatty acids and should be clear showing absence of water and mucilaginous matter. It should be fluid at 40° F. and above. Owing to its high price the oil is very liable to adulteration with peanut oil and cottonseed oil.

The presence of olive oil can be shown by the Elaidin test which is carried out as follows: Dissolve a very little mercury in a little cold concentrated nitric acid. Ten drops of this solution are added to 15 cc. of the oil in a test tube and stirred. After standing one hour a hard, impenetrable yellow mass indicates olive oil. Lard oil shows a fairly hard mass by this test, other oils show softer, buttery masses.

Palm Oil.—This oil is a yellow or orange colored solid at ordinary temperatures. For lubrication, the oil must be tested for free acid as free fatty acids form easily, over 50 per cent. being present at times. In crude samples several per cent. of dirt, trash and water may be present. These can be removed by melting and straining. While palm oil is used considerably abroad, notably in England for railway carriage greases, its use as a lubricant has never been so great in the United States. For grease making, a fairly high percentage of free fatty acids is not undesirable provided the grease is made by converting the fatty acids into a soap.

Peanut Oil (Arachis Oil).—This is classed as a non-drying oil and is sometimes substituted for olive oil. While it has been used very little as a lubricant, it does not gum so much as does rape oil, and so owing to its increased production in the United States it may find some application as a lubricant.

Rape Oil (Rapeseed Oil, Colza Oil).—This is a pale yellow oil with a characteristic odor and taste. It is a semi-drying oil and so has some tendency to gum when used as a lubricant. The free fatty acids usually run from 1 to 6 per cent. Sulphuric acid

may be present in the refined oil. Rape oil is rather difficult to saponify. Rape oil has never had the vogue in the United States it enjoyed abroad, except possibly for blending with heavy mineral oils for use in marine engines. It has a fairly high viscosity and so is used to some extent for compounding cylinder oils. This is particularly true of blown rape oil which has an exceedingly high viscosity and a high specific gravity in which respects it resembles castor oil.

Rosin Oils.—Many grades of these oils are obtained by the distillation of rosin, the usual standard grades being first, second, third and fourth run rosin oils. The first run oil is thicker, of a lighter color, and contains more rosin acids than the later runs. The early runs are therefore more valuable for grease making, *e. g.*, for axle grease. Besides the rosin acids the oils consist largely of hydrocarbon oils. The iodine number varies from around sixty for the first run oil to about twenty for the last runs. The saponification number, which shows the amount of free acid and saponifiable matter present, gives a satisfactory basis for the valuation of the oil for grease making, the oils with high saponification numbers being more valuable for this purpose. First run rosin oils are also known as "Hard Rosin Oils," the other grades being known as medium and soft rosin oils.

When heated, rosin oils have the odor of rosin. They flash around 320° F. and contain from 3 per cent. to 40 per cent. of free acids. The specific gravity varies from 0.96 to 1.02. Crude rosin oils have a fluorescence or "bloom" somewhat like mineral oils. The late runs of rosin oil may be refined by sulphuric acid to yield a lighter colored oil. In this case most of the rosin acids are removed which makes the oil more suitable for lubricating purposes. With the increased price of rosin, and consequently of rosin oils, the chief reason for the use of rosin oil for lubricating oil has been removed. The refined oils have been used widely as lubricating oils, either alone or mixed with mineral oils, but this practice is not advisable as mineral oils fully answer the same purpose.

The presence of rosin oil in fatty oils can be detected by a

decrease in the saponification number and in the flash point, and by an increase in the specific gravity and in the acid number. Its presence in mineral oils is shown by high acid, iodine and Maumené numbers and by the refractive index. Rosin oils are dextro-rotatory and so can be detected by the polariscope. The most satisfactory method for the detection of rosin or rosin oil in any other oil is by the Liebermann-Storch reaction. (See Index.)

Soy-bean Oil.—This oil is now being largely imported into the United States from Manchuria. It is a semi-drying oil and is chiefly used to adulterate linseed oil, for paints and for making soap. It has no use in good lubricating practice owing to its gumming character. Several grades of "blown soy-bean oil" are now on the market. The production of soy-bean oil in the United States is increasing.

BLOWN OILS.

These oils are prepared from rape oil and cottonseed oil by forcing a stream of warm air through the oil heated to over 200° F. A partial oxidation results yielding a product resembling castor oil in viscosity and gravity. The blowing is stopped when the desired viscosity and gravity are obtained. High temperatures give a dark oil, but the blowing is accomplished more quickly. The gravity may be 0.960 to 0.970 or even higher and the viscosity several times higher than castor oil. Since blown rape oil is used chiefly for compounding with mineral oils to make marine engine oils and other engine and cylinder oils it is necessary to limit the blowing as the higher viscosity oils are more difficultly soluble in mineral oils. However, blown oils can be distinguished from castor oil by the fact that they are soluble in light mineral oils. Blown oils have a nauseous odor, a lowered flash point, a lowered iodine number and an increased Maumené number as compared with the corresponding raw oil.

Commercial blown oils are also made from soy-bean oil, corn oil, castor oil, fish oils, and even from the non-drying sperm and tallow oils, although the latter oils are very difficult to oxidize by this process.

DEGRAS OILS.

These oils are usually by-products in treating leather as in the

chamoising process, or recovered wool grease from the scouring of wool. In treating leather, various fish oils are generally used, and the leather is exposed to the air. The oils as recovered from the wash solutions by acid treatment contain oxidized fatty acids or fats, much free fatty acid, much unsaponifiable matter and a high water content. Degras is used in making greases for lubrication, and the degras oil when neutral may be used for compounding cylinder oils.

On account of the varying character of true degras and degras oils, they are open to much adulteration and so should never be used except after thorough test of each lot. The writer has in mind an "acidless degras oil" for compounding cylinder oil, this degras oil being a pure mineral or spindle oil with a degras odor.

TABLE SHOWING PROPERTIES OF ANIMAL AND VEGETABLE OILS.
(Compiled from various standard sources).

	Specific gravity at 60°F.	Average saponification No. (m.g. KOH)	Iodine No. (Hanus)	Average Maumené No. (°C.)	Average solidification point (°C.)	Average solidification point of fatty acids (°C.)
Permissible variation	0.003	3	—	5	5	5
Bone fat	0.915	192	48 to 55	35	16	28
Castor oil	0.964	182	82 " 88	47	—14	3
Corn (Maize) oil	0.923	190	113 " 125	83	16	15
Cottonseed oil	0.924	194	105 " 112	76	— 2	33
Horse oil	0.919	196	74 " 86	50	35	37
Lard	0.935	196	52 " 63	26	29	38
Lard oil	0.916	195	66 " 77	42	3	35
Linseed oil (raw)	0.934	190	171 " 192	124	—20	17
Menhaden oil	0.930	191	145 " 165	125	— 6	---
Neatsfoot oil	0.915	196	65 " 75	46	— 5	26
Olive oil	0.917	190	80 " 87	43	0	21
Palm oil	0.924	197	50 " 56	—	35	41
Peanut (Arachis) oil	0.919	193	85 " 98	58	0	27
Rape (Colza) oil	0.915	174	96 " 103	59	— 5	14
Rosin oils	(0.985)	20–34	(40 " 50)	30	(— 5)	—
Seal oil	0.921	192	130 " 150	92	— 2	18
Soy-bean oil	0.925	191	122 " 135	60	— 5	23
Sperm oil	0.880	130	81 " 88	47	0	14
Tallow	0.946	195	35 " 46	41	35	41
Tallow oil	0.916	196	55 " 57	41	24	—
Whale oil	0.922	190	120 " 135	91	— 4	23

ANIMAL OILS.

The oils and fats from land animals constitute the most valuable of the fixed oils for lubricating purposes.

Bone Fat and Bone Oil.—Bone fat usually contains about 1 per cent. of ash and a large percentage of free fatty acids. Its general properties are somewhat similar to tallow. Bone oil, from bone fat, is somewhat like neatsfoot oil. It has a low cold test and is a good lubricant if the fatty acids are removed.

Horse Oil.—This oil is used to mix with or adulterate other oils used in lubrication and for manufacturing lubricating greases and soaps.

Lard.—This is the solid, rendered fat from pigs. It is chiefly used for edible purposes and for preparing lard oil.

Lard Oil.—This oil is prepared from lard somewhat as tallow oil is prepared from tallow. It is used for general lubrication, and is often seriously adulterated with light petroleum oils before it reaches the ultimate consumer. There are several grades of lard oil, depending on the grade of lard used and the temperature of pressing. The cold test varies considerably. The best grades have very little odor. Only the better grades should be used for compounding.

Menhaden Oil.—This is a fish oil with drying properties. It is used in paints and soaps, but is not generally suitable for lubrication.

Neatsfoot Oil.—This oil consists largely of olein and does not become rancid easily. It is rendered from the feet of cattle. It is used as a lubricant, either alone or in mixtures with mineral oils similar to the use of tallow oil. It is a valuable oil for lubrication.

Porpoise Oil.—There are two varieties, the body oil and the jaw oil, which differ considerably in character. They are used for lubricating watches and other delicate machinery. The two varieties of dolphin or black fish oil find a similar use.

Seal Oil.—This oil is prepared from the blubber of the seal. It is not much used for lubrication as it has drying properties.

Sperm Oil.—This is not a true oil, but a liquid wax. It has the lowest specific gravity of the fixed oils and a low saponification number. It contains no glycerine. While its viscosity is not so high as that of some other oils, it keeps its viscosity unusually well at elevated temperatures. It is excellent for light running machinery, does not corrode, or turn rancid or gum.

Tallows.—Beef tallow is rendered from the fat of cattle, mutton tallow from the fat of sheep and goats. Tallow varies considerably in melting point and other properties, depending on the animal from which it comes, the temperature of rendering, etc. Soft tallows may melt as low as 36° C. while hard tallows may melt as high as 50° C. The free fatty acids usually range from almost none up to 6 per cent. Tallow consists chiefly of olein and stearin. Tallows are valued by the melting or solidification point, the high-melting point tallows being the more valuable. Tallow is used directly as a lubricant in tallow greases, or for soap-making, or for making tallow-soap greases.

Many garbage greases, yellow greases, etc., are sold for purposes similar to tallow. These are valued by their melting point and the amount of saponifiable matter they contain. They usually contain fairly large amounts of unsaponifiable matter.

Tallow Oil.—When tallow is melted and then allowed to remain for some time at approximately 85° F., part of the stearin crystallizes out and can be removed from the oil by filter pressing. The stearin is used for candle and soap making, while the "tallow oil" is used for lubrication and other purposes. The relatively cheaper mineral oils have largely displaced tallow oil as a lubricating oil, except that up to 20 per cent. of tallow oil is still added to mineral oils for steam cylinder lubrication. For this purpose the tallow oil should be "acidless" by actual test.

Whale Oil.—There are a number of varieties of this oil from the blubber of the whale. Only the best grades are suitable for lubrication. In common with most marine animal oils, the odor may be undesirable.

CHAPTER XVIII.

METHODS OF TESTING FATTY OILS.

A. PHYSICAL METHODS.

The **Specific Gravity** of fixed oils is characteristic for each oil and varies only within narrow limits. Any marked variation from the usual specific gravity is an indication of adulteration. The gravity can be taken with a hydrometer, but as considerable accuracy is necessary it is better to use a pycnometer or a Westphal balance, as explained under mineral oils. If the temperature is not at 60° F. a correction of 0.00038 is made for each degree Fahrenheit the temperature is found to differ from 60° F. (For each degree Centigrade the correction is 0.00068.) The correction is to be added if the observed temperature is above 60° F. (15.56° C.)

The **Solidification Point** of fixed oils is very important if the oil is used for lubricating purposes. It is made in the same manner as the cold test or pour test for mineral oils. This is sufficiently accurate for practical purposes. The melting point is usually several degrees higher than the solidification point, which varies considerably for the same oil. Thus tallows vary owing to a variation in the amount of stearin present. The oil does not freeze as a whole, but is solidified by the crystallizing out of some constituent of the oil, usually stearin or palmitin.

The **Solidification Point of the Fatty Acids** can be determined in the same way as for the oils. A very simple method for making the melting point determination is to put some of the melted acids in a capillary tube closed at one end, letting cool for several hours, fastening the tube with the closed end opposite the bulb of a thermometer, immersing in a water bath which is slowly heated, and noting the temperature at which the fatty acids become clear.

The fatty acids for the above test can be prepared by saponifying 50 grams of the oil with about 50 cc. of 30 per cent. caustic soda solution to which about 50 cc. of alcohol has been added.

The mixture is evaporated to dryness over a very low flame so as to prevent scorching. The soap is then dissolved in some 600 cc. of water, and boiled for some time after the soap is completely dissolved to insure the removal of the alcohol. If the solution is not clear, or great accuracy is desired, the solution is cooled and the unsaponifiable matter removed by shaking out with ether. Finally about 100 cc. of 20 per cent. sulphuric acid is added to the hot soap solution to set the fatty acids free. Boil until the fatty acids collect on top of the water, remove the fatty acids and wash free of sulphuric acid by means of hot water. Heat the acids in a dish on the water bath until clear and free from water.

A determination of the **Refractive Index** of oils by means of the Abbé Refractometer or the Zeiss Butyro-Refractometer gives valuable data for determining the purity and character of an oil. This determination is easily and quickly made, and so is especially valuable in the routine examination of a large number of oils. The refractive index for any fixed oil varies only between narrow limits.

The **Flash Point** of natural fixed oils is usually above 500° F. with the open cup. Only blown oils, rosin oils, and sometimes neatsfoot oil have lower flash tests.

The **Viscosity** determination is of value in certain cases, as with blown oils, rape oil, castor oil and sperm oil.

The approximate Saybolt viscosities of some fatty oils are as follows:

	100°F.	210°F.
Refined rape oil	255	64
Castor oil	1,350	105
Lard oil	210	—
Neatsfoot oil	215	57
Sperm oil	98	46
Tallow (hard, beef)	—	59

B. CHEMICAL METHODS.

The chief chemical tests for these oils are the determination of the saponification number, the iodine number, the Maumené

number, the amount of free fatty acid, and a few other special determinations.

The **Saponification Number** (or Koettstorfer value) is the number of milligrams of caustic potash required to saponify 1 gram of the oil or fat. The number for most oils varies around 190 to 195; that is, most oils require from 19.0 to 19.5 per cent. of caustic potash to saponify them completely. Some oils, like castor oil, rape oil and sperm oil, have much lower numbers.

The saponification number is determined as follows: Weigh 2 grams of the oil or filtered fat into a clean 200 cc. Erlenmeyer flask. Measure into the flask exactly 25 cc. of clear alcoholic potash (containing about 40 grams of KOH in a liter of 95 per cent. alcohol). A second flask is prepared at the same time and in the same way except that no oil is added. Connect the flask with a reflux condenser and boil on a water bath for 30 minutes or until saponification is complete. Cool and titrate with half-normal acid (HCl) using phenolphthalein as indicator. To calculate the saponification number, subtract the number of cubic centimeters of half-normal acid used in the titration from the number of cubic centimeters of half-normal acid used to titrate the "blank," multiply the result by 28.05 and divide by the number of grams of oil used.

A simple qualitative saponification can be carried out by putting a little of the oil in a flask, adding a short stick of caustic potash and a small amount of alcohol. Heat on a water bath for a half hour using a glass tube as a reflux condenser. Pour the mixture at once into a large beaker of water; a clear solution indicates freedom from mineral oils, a turbid solution indicates the presence of mineral oil or rosin oil.

Iodine Number.—This is the most important single determination for detecting the character of an oil. The Hanus method for determining the iodine number is as follows: Weigh out accurately from 0.12 to 0.25 gram of the oil, using the smaller amount for drying oils. For fats or mineral oils from 0.50 to 1.00 gram may be used. The amount of oil should be small enough so that not over 40 per cent. of the iodine solution will

be used up. The oil can be weighed best by difference. Dissolve the weighed oil in a 250 cc. glass-stoppered flask by means of 10 cc. of chloroform. Now add 25 cc. of the Hanus iodine solution. Prepare a "blank" in the same way with exactly the same amount of iodine solution, draining the pipette carefully in each case. Let stand with occasional shaking for 30 minutes without exposing to strong light. At the end of just 30 minutes add 10 cc. of 15 per cent. potassium iodide solution, mix, add about 100 cc. of water and titrate with N/10 sodium thiosulphate solution. As the color fades add a little fresh starch solution and titrate slowly until the blue color disappears. The flask should be well shaken just before the end of the titration.

Calculate the iodine number as follows: Subtract the number of cubic centimeters of the thiosulphate solution required for the titration from the number of cubic centimeters of thiosulphate solution used to titrate the blank, multiply the result by 1.27 and divide by the amount of oil used.

The Hübl and the Wijs methods for determining the iodine number give approximately the same results as the Hanus method. Mineral oils have a very low iodine number, usually 8 to 16, or even higher for cracked oils, while fatty oils show a range from about 35 up to 200. The iodine number shows the degree of saturation of the oil, particularly the degree of saturation of the fatty acids. Oils with an iodine number much over 100 are not usually suitable for lubricating oils on account of their drying character which causes the oil to gum.

The **Maumené Number** is quickly and easily determined and often gives valuable information. Fifty grams of the oil are weighed into a tall beaker, the exact temperature of the oil noted, and 10 cc. of concentrated sulphuric acid at the same temperature are run in gradually with stirring. The beaker is protected as much as possible against loss of heat. The stirring is continued and the highest temperature noted, being careful to wait sufficiently long to be certain of the highest temperature. The rise in temperature expressed in degrees Centigrade is the Maumené number. It is usually roughly in proportion to the iodine number. It is very important that strong sulphuric acid, at least 96

per cent. be used. Such an acid will show a Maumené number of about 44 when tested with water instead of with oil.

Mineral oils usually give Maumené numbers from three to six. Higher values indicate the addition of rosin or fatty oils. Rosin oils usually give numbers around 30. Cylinder oil stocks have a Maumené number of four or five, while compounded cylinder oils have a Maumené number from seven to twelve.

When the temperature is found to rise much above 60° C. the test should be repeated using a mixture of equal parts of pure light mineral oil and the unknown oil. Subtract two from the rise of temperature and multiply by two to get the Maumené number.

Free Fatty Acids are usually present in varying amounts in fatty oils and may cause serious corrosion of machinery especially in the presence of water or at elevated temperatures, as in steam cylinder lubrication. From 2 to 3 per cent. of free fatty acids calculated as oleic acid should be about the maximum for fatty oils for lubricating purposes.

To determine the per cent. of free fatty acids, weigh out 10 grams of the oil into a flask, add about 60 cc. of alcohol, connect the flask with a dry reflux condenser and warm on a water-bath for a few minutes. Shake well, cool and titrate with N/5 caustic potash using phenolphthalein as indicator. The end-point is a permanent pink color after shaking the flask vigorously. A blank should be run in the same way and the proper correction made if the alcohol does not prove to have been neutral. To calculate the per cent. of "free oleic acid" multiply the number of cubic centimeters of N/5 caustic solution by 5.64 and divide by the number of grams of oil used.

Sometimes the fatty acids are reported as "acid number" which is the number of milligrams of KOH required to neutralize the free acids in 1 gram of the oil. This "acid number" can be calculated by multiplying the "free oleic acid" by 2. (For other methods for determining free fatty acids, see Index.)

The **Reichert-Meissl Number** is important for testing certain oils which contain notable percentages of volatile fatty acids

soluble in water. Such oils as cocoanut oil, palmnut oil, porpoise oil, dolphin jaw oil, lard oil, blown oils, croton oil and butter show characteristically large amounts of such fatty acids by this test. The Reichert-Meissl number for these oils is over six while for most other oils the number is one or less. The Reichert-Meissl number is the number of cubic centimeters of N/10 caustic potash required to neutralize the volatile, water-soluble fatty acids obtained by a standard procedure from 5 grams of oil. See other texts for method of making the test which is not often necessary in testing lubricants.

Color Tests.—A large number of color tests for special oil have been devised, but most of these tests are unreliable. Only the best of these are given.

The **Liebermann-Storch Reaction** is reliable for detecting rosin or rosin oils, especially in mineral oils. About 2 cc. of the oil are gently heated in a test tube with 4 cc. of acetic anhydride. Cool, filter so as to remove the oil and add to the clear filtrate 1 drop of sulphuric acid made by mixing equal volumes of concentrated sulphuric acid and water. If rosin is present a fine fugitive violet color is produced at once. Some animal oils, particularly fish oils, and a few vegetable oils may give a similar test. The quantitative estimation of rosin or rosin oils is best made by Twitchell's method, but this method will not be described as the qualitative detection is usually sufficient.

The **Halphen Test** for cottonseed oil is a reliable color test except that cottonseed oil which has been heated to 250° C. and blown cottonseed oil do not give the test. Two cc. each of the oil, amyl alcohol, and a 1 per cent. solution of carbon disulphide are heated in a test tube in a boiling water bath for 20 to 30 minutes. As much as 5 per cent. of cottonseed oil gives a characteristic deep red color. Fat from cattle which have been fed on cottonseed meal may give the test.

The **Bechi or Silver Nitrate Test** is another characteristic reaction for cottonseed oil, although it has the same limitations as the Halphen test and is not quite so reliable. It is a very delicate test showing as little as 5 per cent. of cottonseed oil. Make a 1

per cent. solution of silver nitrate in 95 per cent. alcohol free from aldehyde and add about half as much ether as alcohol. Add 1 drop of nitric acid to a 100 cc. of this solution. Upon heating 10 cc. of the oil with about 5 cc. of the above reagent, using a test tube immersed in boiling water for about 20 minutes, a darkening will be observed in the presence of cottonseed oil owing to the reduction of the silver nitrate. The darkening is proportional to the amount of cottonseed oil present. Rancid oils or animal oils rendered at too high a temperature may also give the reaction. The test is more reliable if carried out on the separated fatty acids instead of on the oil.

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CHAPTER XIX.

SPECIFICATIONS FOR FATTY OILS.

Castor Oil.—(Navy Department, Nov. 1, 1915.*) Castor oil should present a pale, yellowish, or almost colorless, transparent appearance; should have at ordinary temperatures a thick, sluggish, viscous consistency, and should give off at first a faint, mild odor, becoming soon after slightly acrid and offensive.

The castor oil furnished under this specification will meet the following requirements:

(*a*) Specific gravity at 60° F., 0.960 to 0.965.

(*b*) Have a saponification number between 179 and 184.

(*c*) Must be soluble in equal volume of alcohol and in all proportions in absolute alcohol or glacial acetic acid.

(*d*) Must be insoluble in petroleum ether at a temperature of 60° F. or below. (Supplied in specified cans and cases.)

Cottonseed Oil.—(Navy Department, May 1, 1916.) To be thoroughly refined winter-pressed cottonseed oil; to stand a 5-hour cold test. Must be sweet, neutral in flavor and odor, and free from rancidity. To have a refractive index at 25° C. of not less than 1.47 and not more than 1.4725, and an iodine number of not less than 104 and not to exceed 110. (Packed in specified 1-gallon cans, labelled, and packed eight cans per case.)

Each bid is submitted with the distinct understanding that the cottonseed oil is guaranteed to keep good in any climate for a period of one year after date of delivery at the navy yard.

Fish Oil.—(Navy Department, Aug. 1, 1914.) To be strictly pure winter-strained, bleached, air-blown menhaden fish oil, free from adulteration of any kind.

The oil should show upon examination:

	Maximum	Minimum
Specific gravity	0.935	0.930
Iodine number (Hanus)	165	145
Acid number	6	—

* All Navy Department specifications are from the Bureau of Supplies and Accounts.

The oil when poured on a glass plate and allowed to drain and dry in a vertical position, guarded from dust and exposure to weather, shall be practically free from tack in less than 75 hours at a temperature of 70° F. When chilled, the oil shall flow at temperatures as low as 32° F.

To be purchased by the commercial gallon; to be inspected by weight and the number of gallons to be determined at the rate of 7½ pounds of oil per gallon. (Delivered in barrels.)

Lard Oil (For Pipe Cutting and Threading Purposes).—(Navy Department, Oct. 1, 1915.) Shall be a clear, light yellow lard oil of good quality, free from rancidity or adulteration. It shall not contain more free fatty acid than 5 per cent. of oleic acid.

The specific gravity at 15° C. shall be not lower than 90 per cent. or higher than 92 per cent. It shall flow at 8° C. or below. Its viscosity at 38° C. shall not exceed 220 seconds in a Saybolt viscosimeter having a water rate of 30 seconds at 15° C. (Deliveries in 50-gallon casks.)

Lard Oil.—(War Department, Depot Quartermaster, New York City, Feb. 1, 1909.) Must be a pure lard oil of the best quality.

Must have a specific gravity between 0.910 and 0.916 at 60° F.

Must not solidify above 42° F.

When saponified with alcoholic caustic potash the resulting soap must be completely soluble in water showing no turbidity.

Must not show more acidity than the equivalent of 2 per cent. oleic acid.

Must not show an orange or reddish-brown color when 5 cc. of oil is shaken thoroughly with 5 cc. of nitric acid (sp. gr. 1.37) and allowed to stand 24 hours. (A check test should be made at the same time with an oil of known purity.)

Must be no color change when 5 cc. of oil is shaken thoroughly in a test tube with 5 cc. of an alcoholic solution of silver nitrate (made by dissolving 0.1 gram of silver nitrate in 10 cc. of pure 95 per cent. alcohol and adding 2 drops of nitric acid), and the mixture heated for five minutes in a water bath.

Quart samples must be submitted with bid.

Lard Oil.—(Norfolk & Western Railway, Motive Power Dept., Roanoke, Va., Feb. 27, 1912.) Two grades of lard oil, known

in the market as extra (or prime), and extra No. 1 will be purchased.

When the shipment is received a sample will be taken from any barrel at random, and the oil accepted or rejected on this test. The right will be reserved, however, to inspect any and all barrels.

Extra lard oil will not be accepted which:

1. Contains mixtures of other oils.
2. Contains more than 2 per cent. of free acid.
3. Shows a discoloration with the silver nitrate test.
4. Has a cold test above 45° F. between Oct. 1 and April 1.

Extra No. 1 lard oil will not be accepted which:

1. Contains mixtures of other oils.
2. Contains more than 12 per cent. free acid.
3. Has a cold test above 45° F. between Oct. 1 and April 1.

The standard purity test will be Maumené test, or rise of temperature with sulphuric acid. Should any doubt arise, however, the right to use any test, such as specific gravity, refractive index, iodine absorption, or Halphen's test, is reserved. (Methods specified for free acid, for the silver nitrate test, and for the cold test.)

Lard Oil.—(Pennsylvania Railroad, Office Gen. Supt. of Motive Power, April 14, 1904.) Two grades of lard oil, known in market as "Extra" and "Extra No. 1," will be used, the former principally for burning and the latter as a lubricant.

The material desired under this specification is oil from the lard of corn fed hogs, unmixed with other oils, and containing the least possible amount of free acid. Also from Oct. 1 to May 1 it should show a cold test not higher than 40° F. Oil from lard of "mast" or distillery fed hogs does not give good results in service, and should never be sent. Also care should be taken to have the oil made from fresh lard. Old lard gives an oil that does not burn well, and also gums badly as a lubricant. The use of the so-called neatsfoot stock, either alone or as an admixture in making the "Extra No. 1" grade, is not recommended. Neatsfoot oil is used by the railroad company when the price will admit, but it is preferred to have it unmixed.

Shipments must be made as soon as possible after the order is placed. Also shipments received at any shop after Oct. 1 will be subjected to the cold test and rejected if they fail, unless it can be shown that the shipment has been more than a week in transit.

Shipments of the "Extra" grade will not be accepted which:

1. Contain admixture of any other oils.
2. Contain more free acid than is neutralized by 4 cc. of alkali as described in the printed method. (See under tallow oil for P. R. R.)
3. Show a cold test above 45° F. from Oct. 1 to May 1.
4. Show coloration when tested with nitrate of silver as described below.

Shipments of "Extra No. 1" grade will not be accepted, which:

1. Contain admixtures of any other oils.
2. Contain more free acid than is neutralized by 20 cc. of alkali as described in the printed method.
3. Show a cold test above 45° F. from Oct. 1 to May 1.

The cold test and the amount of free acid must be determined in accordance with Pennsylvania Railroad standard methods.

The nitrate of silver test is as follows: Have ready a solution of nitrate of silver in alcohol and ether, made on the following formula:

Nitrate of silver	1 gram
Alcohol	200 grams
Ether	40 grams

After the ingredients are mixed and dissolved, allow the solution to stand in the sun or in diffused light until it has become perfectly clear; it is then ready for use and should be kept in a dimly lighted place and tightly corked.

Into a 50 cc. test tube, put 10 cc. of the oil to be tested (which should have been previously filtered through washed filter paper), and 5 cc. of the above solution, shake thoroughly and heat in a

vessel of boiling water 15 minutes with occasional shaking. Satisfactory oil shows no change of color under this test.

Shippers must pay freight charges both ways on rejected material.

Lard Oil.—(Seaboard Air Line Railway, Motive Power Dept., July 7, 1915.) Lard oil will be obtained in two grades—No. 1 and No. 2.

No. 1. This grade will be used chiefly for burning.

It must be light yellow in color and contain no other oil mixture or sediment of any kind.

It must have gravity of between 23° and 24° Bé., at 60° F., and not show on titration more than 3 per cent. free fat acid.

No. 2. This grade will be used about shops on turret lathes, cutting threads, staybolt cutters, etc.

It may be reddish in appearance, but preference will be given to oils that are lighter in color.

It must contain no mixture with other oil than lard, or more than a trace of sediment. Gravity approximately as above defined for No. 1 grade.

On titration it must not show more than 15 per cent. free fat acid.

Such tests will be applied to either of above grades as will satisfy the inspector that no other oils than lard are contained in admixture with the samples submitted.

Shipments which do not conform to this specification will be rejected. In cases of rejection the materials will be held for two weeks from the date of test. If by the end of that period the manufacturers have not given shipping directions, it will be returned to them at their risk, they paying freight both ways.

Linseed Oil (Raw).—(Navy Dept., Aug. 2, 1915.) Raw linseed oil shall be strictly pure, well-settled oil, perfectly clear and free from foots.

The oil shall show upon examination:

	Maximum Per cent.	Minimum Per cent.
Loss on heating one-half hour at 103 to 105°C.	0.2	—
Specific gravity at 15.5°C.	0.937	0.932
Iodine number (Hanus)	190.	178.
Saponification number	192.	189.
Acid number	3.	—
Refractive index at 25° C.	1.4805	1.479
Unsaponifiable matter	1.5	—

The oil when flowed on a glass plate, which is held in a position inclined 30° to the vertical, shall dry practically free from tackiness in 75 hours at a temperature of 60° to 80° F.

To be purchased by the commercial gallon and inspected by weight. The number of gallons to be determined at the rate of 7½ pounds of oil to the gallon. (Detailed specifications given for cans, packing and method of inspection.)

Linseed Oil (Raw).—(War Dept., Office of the Depot Quartermaster, New York City, Jan. 2, 1908.) Must be absolutely pure, well settled oil of best quality, must be perfectly clear at a temperature of 60° F. and not show a loss of over 2 per cent. when heated at 212° F., or show any deposit of "foots" after being heated to this temperature. The specific gravity must be between 0.932 and 0.937 at 60° F.

Must not have a flash point below 470° F.

Must give a reddish-brown clot when 20 cc. of oil is treated with 1 cc. concentrated sulphuric acid.

Quart sample must be submitted with bid.

Linseed Oil (Boiled).—(Navy Dept., June 1, 1916.) Boiled linseed oil shall be strictly pure boiled oil of high grade, made wholly by heating pure linseed oil to over 350° F. with oxides of lead and manganese for a sufficient length of time to secure a proper combination of the constituents and shall be properly clarified by settling or other suitable treatment. Evidence of the presence of any matter not resulting solely from the combination of the linseed oil with the oxides of lead and manganese will be considered grounds for rejection.

The oil shall upon examination show:

Unsaponifiable matter	Not more than 1.5 per cent.
Lead oxide (PbO)	Not less than 0.20 per cent.
Manganese oxide (MnO)	Not less than 0.04 per cent.
Iodine No. (Hanus)	Not less than 178.
Specific gravity at 60°F.	Not less than 0.938.

The oil shall give no appreciable loss at 212° F. in a current of hydrogen.

The oil when flowed on a glass plate held in a position inclined 30° to the vertical, shall dry practically free from tackiness in 12 hours at a temperature of 60° to 80° F. (Method of packing and inspection by weight given in detail.)

Linseed Oil (Boiled).—(War Dept., Depot Quartermaster's Office, New York City, Jan. 2, 1908.) Must be absolutely pure kettle boiled oil of the best quality, and the film left after flowing the oil over glass and allowing it to drain in a vertical position must dry free from tackiness in 12 hours at a temperature of 70° F.

The specific gravity must be between 0.934 and 0.940 at 60° F.

Must not have a flash point below 470° F.

Must show a firm clot when 20 cc. of oil is treated with 1 cc. of concentrated sulphuric acid and on standing no appreciable amount of scum should form on top of oil.

Must not show a fugitive violet color with 2 cc. of oil shaken with 5 cc. of acetic anhydride at a gentle heat; and after cooling the acetic anhydride is drawn off by means of a pipette and a drop of sulphuric acid (specific gravity 1.53) added.

Neatsfoot Oil.—(Navy Dept., Jan. 2, 1917.) Neatsfoot oil must be free from admixture of other oils, and must not contain more acidity than the equivalent of 2 per cent. of oleic acid.

It must have a cold test below 25° C., as determined in the following manner: A couple of ounces of the oil will be put in a 4-ounce sample bottle and a thermometer placed in it. The oil will then be frozen, using a freezing mixture of ice and salt if necessary. When the oil has become hard the bottle will be re-

moved from the freezing mixture and the oil allowed to soften, being stirred and thoroughly mixed at the same time by means of the thermometer until the mass will run from one end of the bottle to the other. The reading of the thermometer at this moment will be taken as the cold test of the oil.

Before acceptance the oil will be inspected. Samples of each lot will be taken at random, the samples well mixed together in a clean vessel, and the sample for test taken from this mixture. Should the mixture be found to contain any impurities or adulterations, the whole delivery of oil it represents will be rejected, and it is to be removed by the contractor at his own expense.

Each delivery will be considered a lot by itself and each lot will be inspected and accepted or rejected as it passes or fails to pass the test required. No second test of any lot rejected will be permitted. (Delivery to be made in specified cans and cases. Part of cans will be weighed full and empty.)

Sperm Oil.—(Navy Dept., Oct. 2, 1916.) Must be pure winter strained bleached sperm oil, free from admixture or adulteration with animal, mineral, vegetable, or other fish oil, grease, lard, or tallow, or any other adulterant.

The specific gravity must be between 0.875 and 0.885. The flash test of the oil in open cup must not be under 440° F. The oil must show less acidity specifically than the equivalent of 0.25 per cent. of oleic acid. To be purchased and inspected by weight; the number of pounds per gallon to be determined by the specific gravity of the oil at 60° F. multiplied by 8.33 pounds, the weight of a gallon (231 cubic inches) of distilled water at the same temperature.

(Method of inspection, sampling, weighing and rejection substantially as given in the last two paragraphs under neatsfoot oil above. (Packed in white oak casks.)

Sperm Oil (Natural).—(War Dept., Office Depot Quartermaster, New York City, January, 1915.) Must be absolutely pure natural winter sperm oil of best quality and must conform to the following tests:

Specific gravity	0.875-0.884 at 60°F.
Saponification value	123 - 147.
Iodine value	82 - 85.
Maumené test	81°- 85°F.
Color	Light straw.
Odor	Slight and sweet.
Flash	Must not flash below 485°F.
Cold test	Must flow at a temperature of 38°F.

Quart samples must be submitted with bid.

Sperm Oil (Bleached).—(War Dept., Office Depot Quartermaster, New York City, January, 1915.) (Specifications as for sperm oil, natural, except that color is "pale yellow," odor "none," flash "not below 500° F.," and test for acidity "must show less than the equivalent of 0.25 per cent. of oleic acid.)

Tallow.—(Navy Dept., June 1, 1914.) To be a high-grade tallow, pure and refined, free from rancidity, dirt, cracklings, soap, or other substances not properly belonging to tallow.

To be free from more acidity than the equivalent of 2 per cent. of oleic acid, and the mixed fatty acids to titer not less than 42° C.

Payment will be based on net weight, and net weight only should be delivered. (To be delivered in specified soldered top tins, to be boxed and marked as specified.)

Tallow.—(Norfolk & Western Railway, Office Supt. of Motive Power, Roanoke, Va., April 15, 1912.) The material desired under this specification should be made from beef or sheep fat, free from cottonseed stearines and wool grease, and should be rendered within 12 hours after the animal is killed, at a temperature not in excess of 250° F. It should be as near white in color as is possible to obtain, firm, of good odor, and free from granulation.

When a shipment of this material is received, a sample will be taken in such a manner as will represent the average condition of the entire lot, and acceptance or rejection will be based upon the results of the examination of this sample.

Material will not be accepted which upon examination shows:

1. Dirt or crackings disseminated through it or in streaks, or which has a layer of dirt or cracklings at the bottom of the cake or cakes more than 1/8 inch thick.
2. An amount of free acid, determined in accordance with method outlined below, in excess of 1.5 per cent.
3. Soap or other substances not properly belonging to the material, or more than 0.5 per cent. of animal tissue.

The free acid is determined as follows: Take 2 ounces of neutral 95 per cent. alcohol, and add a few drops of phenolphthalein solution. Heat to 150° F., then add 10 grams of the material. Shake the contents of the flask until solution of the tallow is effected, cool, and titrate with decinormal sodium hydrate until the color of the solution remains a permanent pink. From the number of cubic centimeters of decinormal solution required (1 cc. N/10 NaOH equals 0.0282 gram oleic acid) the percentage of free acid is obtained.

All material failing to conform to the requirements of this specification will be rejected and returned to the shipper, he being required to pay all freight charges both ways.

Tallow.—(Pennsylvania Railroad, Office Gen. Supt. Motive Power, Altoona, Pa., April 29, 1913.) Tallow according to this specification will be ordered in amounts as the demands of the service indicate.

The material desired under this specification is a tallow containing the least possible amount of free acid, and also as free as possible from dirt, "cracklings" and fiber.

To persons furnishing tallow who may not have appliances for determining the amount of free acid in tallow, it may be said that if the fat is rendered within 12 hours from the time the animal is killed, using a temperature of not more than 225° to 250° F. during the rendering, it is believed that the free acid in the tallow will be less than the amount specified. In very warm weather it may be necessary to render the fat in less than 12 hours after the animal is killed.

A shipment being received at any point, a sample of not less than 1/2 pound must be sent to the chief chemist, Pennsylvania

Railroad, Altoona, Pa., by railroad service, in a "sample for test" box, accompanied by a "sample for test" tag properly filled out, and the tallow must not be used until report of test is received. A sample must be sent for test from every shipment of 1,000 pounds or less, and if more than 2,000 pounds are in the shipment, three samples must be sent, and so on. These large shipments must be divided into parts corresponding to the number of samples, and a designating mark put on each part and the same mark on the tag of its sample.

Shipments of tallow will not be accepted which:

1. On inspection, are found to contain dirt or "cracklings" disseminated through the material in the barrels, or in streaks, or which have a layer of dirt or "cracklings" in the bottom of the barrel more than 1/8 inch thick.
2. Contain more free acid than is neutralized by three (3) cc. of alkali as described below.
3. Contain soap or other substances not properly belonging to tallow.

The amount of free acid in tallow is determined as follows: Have ready (1) a quantity of 95 per cent. alcohol, to which a few grains of carbonate of soda has been added, thoroughly shake and allow to settle; (2) a small amount of turmeric solution; (3) caustic potash solution of such strength that 31½ cc. exactly neutralizes 5 cc. of a solution of sulphuric acid and water, containing 49 milligrams of H_2SO_4 per cubic centimeter. Now weigh or measure into any suitable closed vessel, a 4-ounce sample bottle for example, 8.9 grams of the melted tallow. Add about 2 ounces of the alcohol, warmed to about 150° F., add a few drops of the turmeric solution and shake thoroughly. The color becomes yellow. Then add from a burette graduated to cubic centimeters, the caustic potash solution, little at a time with frequent shaking, until the color changes to red, which red color must remain permanent after the last vigorous shaking. The number of cubic centimeters used, shows whether the tallow stands test or not.

Ten cc. of melted tallow at 100° F., weigh almost exactly 8.9

grams. In ordinary work, therefore, it will probably not be necessary to weigh the tallow. Measurement with a 10 cc. pipette will usually be sufficiently accurate, provided the pipette is warmed to about 250° F., and allowed to drain, the last drops being blown out. In case of dispute, however, the balance must be used.

Samples of rejected material are usually held at the laboratory one month from date of test report. Accordingly, in case of dissatisfaction with the results of test, the shippers must make claims for rehearing, should they desire to do so, within that time. Failure to raise a question for one month will be construed as evidence of satisfaction with the tests, the samples will be scrapped, and no claims for rehearing will be considered.

Tallow.—(Seaboard Air Line Railway, Motive Power Dept., July 7, 1915.) Tallow will be furnished in either of the two grades, No. 1 or No. 2, as ordered.

No. 1 Tallow. The material desired under this specification is clear white tallow, as free from acid, dirt or cracklings as possible. Material must meet the following requirements and will be condemned if:

1. Sample shows dirt or cracklings disseminated through it or in streaks, or if the barrel from which sample was taken has a layer of dirt or cracklings in the bottom more than 1/8 inch in thickness.
2. Sample contains more than 1.5 per cent. of free acid.
3. Sample contains soap, or any other substance not properly belonging to tallow.
4. Sample has a melting point below 120° F. or above 125° F.

No. 2 Tallow. This material will be obtained for common uses, such as skidding lumber, protecting iron surface from rust, moving heavy machinery, etc. It is not to be used for lubrication of machinery, compounding hot box grease, or for use in shipyard around copper bottoms. The material desired in this specification is a clear, nearly white tallow, as free from dirt and cracklings as possible. The material must meet the following requirements, and will be condemned if:

1. Sample shows dirt or cracklings disseminated through it or in streaks, or if the barrel from which samples are taken has a layer of dirt or cracklings in the bottom more than ¼ inch thick.
2. Sample contains more than 10 per cent. free acid.
3. Sample contains soap or any substance not properly belonging to tallow.
4. Sample has a melting point below 110° F. or above 120° F.

Tallow will not be accepted that is rancid. It must be free from odor of decomposition.

Remarks: Tallow not meeting the requirements of the above specifications will be condemned. In case of rejection the materials will be held for two weeks from the date of test. If by the end of that period the manufacturers have not given shipping directions, it will be returned to them at their risk, they paying the freight both ways.

Whale Oil.—(Navy Dept., April 20, 1910.) Must be best grade of winter strained oil, free from adulterations with other oils.

Tested with litmus paper, it must show no trace of acid.

It will begin to become torpid at from 35° to 42° F. and cease to flow at from 17° to 18° F.

Specific gravity at 60° F., from 0.9151 to 0.9174; to be purchased and inspected by weight, the number of pounds per gallon to be determined by the specific gravity of the oil at 60° F. multiplied by 8.33 pounds, the weight of a gallon (231 cubic inches) of distilled water at the same temperature.

Oils must be accompanied by a guaranty from the manufacturer that it is pure whale oil.

Before acceptance the oil will be inspected. Samples of each lot will be taken at random, the samples well mixed together in a clean vessel, and the sample for test taken from this mixture. Should the mixture be found to contain any impurities or adulterations, the whole delivery of oil it represents will be rejected.

CHAPTER XX.

SPECIFICATIONS FOR CYLINDER OILS.

Cylinder Oil, Light.—(War Dept., Depot Quartermaster, New York City, Jan. 2, 1908.) This oil is suitable where a light-colored valve oil is desired.

Must be a compounded oil composed of 15 per cent. pure acidless tallow oil and 85 per cent. pure filtered mineral oil. Must be free from acid, alkali, tarry or suspended matter, and must satisfactorily pass the following tests:

Specific Gravity.—Must not be less than 0.981 nor more than 0.895 at 60° F. [26.4° to 27.1° Bé.]

Flash.—Must not flash below 470° F.

Fire.—Must not burn below 540° F.

Viscosity.—Must not be less than 2.30 at 100° C. (Engler.) [Approximately 81 Saybolt at 210° F.]

Cold Test.—Must flow at a temperature of 36° F.

Acid.—Must not give an acid reaction on polished copper in 24 hours.

Alkali.—Must not show an alkaline reaction.

Water.—Must not froth or bump when heated in flash cup.

Tarry and Suspended Matter.—Put 5 cc. oil in 100 cc. stoppered measuring flask and 95 cc. benzine. Shake well and allow to stand at least 10 minutes. There must be no precipitation.

Volatility.—Heat small quantity of oil on watch glass, for two hours at 400° F. There must not be a loss of more than 5 per cent. by weight.

Saponification.—When oil is treated with alcoholic potash, must show the presence of 15 per cent. tallow oil.

Quart samples must be submitted.

Cylinder Oil, Dark.—(War Dept., Depot Quartermaster, New York City, Jan. 2, 1908.) This oil is suitable where steam pressures are high and lubricating conditions severe.

Must be a compounded oil composed of 5 per cent. pure acidless tallow oil and 95 per cent. mineral oil. Must be free from acid, alkali, tarry or suspended matter, and must satisfactorily pass the following tests:

Specific Gravity.—Must not be less than 0.900 nor more than 0.905 at 60° F. [24.7° to 25.5 Bé.]

Flash.—Must not flash below 540° F.

Fire.—Must not burn below 600° F.

Viscosity.—Must not be less than 3.83 at 100° C. (Engler.) [Approximately 142 Saybolt at 210° F.]

(Other tests as for light cylinder oil above, except that saponification must show the presence of 5 per cent. tallow oil and no cold test is specified.)

Cylinder Oil, "Ammo."—(War Dept., Depot Quartermaster, New York City, Jan. 2, 1908.) This oil is suitable for use in ammonia cylinders of ice and refrigerating machinery.

Must be a pure filtered mineral oil. Must be free from acid, alkali, suspended matter, and satisfactorily pass the following tests:

Specific Gravity.—Must not be less than 0.870 nor more than 0.875 at 60° F. [30° to 31° Bé.]

Flash.—Must not flash below 370° F.

Fire.—Must not burn below 420° F.

Viscosity.—Must not be less than 2.38 at 50° C. (Engler.) [Approximately 84 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 5° F.

(Acid, alkali and water tests as described for war department light cylinder oil above. Must show no saponification.)

Cylinder Oil, "Westo."—(War Dept., Depot Quartermaster, New York City, Jan. 2, 1908.) This oil is suitable for use in cylinders of Westinghouse engines.

Must be a pure mineral oil and pass satisfactorily the following tests:

Specific Gravity.—Must not be less than 0.893 nor more than 0.899 at 60° F. [25.7° to 26.8° Bé.]

Flash.—Must not flash below 450° F.

Fire.—Must not burn below 540° F.

Viscosity.—Must not be less than 3.11 at 100° C. (Engler.) [About 113 Saybolt at 210° F.]

(Other tests as given under war department light cylinder oil above. No cold test specified, and must show no saponification.)

Cylinder Oil No. 3.—(Baltimore & Ohio Railroad, Motive Power Dept., Baltimore, Md., April 27, 1914.) This is for use in isolated water pumping plants and other places where low pressure saturated steam is used and a high grade cylinder oil is not required.

This material will be tested and inspected on its arrival at destination by the B. & O. Test Bureau, and the decision of the engineer of tests, as to its acceptance or rejection, shall be final.

(*a*) The oil must be a mixture of pure petroleum distillate and acidless animal oil (tallow oil preferred), unmixed with any other substance, and meet the requirements of the following detail specifications.

(*b*) This material will be purchased by weight. Barrels must be in good condition, and must have the name of contents and consignor's name and address on each barrel, and plainly marked with the gross and net weights. This applies to oil tank cars as well as barrels. Parties failing to mark both gross and tare weights on their packages must accept this Company's weights without question.

(*c*) When received, all shipments will be promptly weighed. If not practicable to empty all barrels, 5 per cent. will be emptied, and the losses of the whole shipment will be adjusted in accordance with the 5 per cent. taken. Should the net weight taken be less by 1 per cent. than the weight charged on bill, a reduction will be made for all over 1 per cent. This 1 per cent. covers leakage in transit, and the amount which adheres to the barrels in emptying; also possible slight difference in scales.

(*d*) Price should be given in cents and hundredths of a cent per pound.

(*e*) Shipments, one or more barrels of which are filled with oil containing dirt, water or other impurities, will be rejected.

When a shipment is received, a single sample will be taken at random from any barrel and subjected to test, and shipment will be accepted or rejected on this sample.

(*a*) It must show not less than 5 per cent. acidless animal oil.

(*b*) It must have a flash test of at least 450° F.

(*c*) It must have a fire test not below 500° F.

(*d*) It must have a cold test below 55° F.

(*e*) The gravity must be between 21° and 27° Bé. at 60° F.

(*f*) It must contain not more than 0.10 per cent. free fatty acid.

(*g*) It must be free from dirt, specks, lumps, grit, wax, water, soap or suspended matter of any kind, acid or alkali.

(*h*) Must not contain more than 3 per cent. volatile matter at 400° F. in two hours.

(*i*) The viscosity at 210° F. must not be less than 100 seconds when tested in a Universal Saybolt Viscosimeter.

The "Cleveland" open cup is used for determining the flash and burning point of this oil, heating the oil at the rate of about 15° per minute and applying the test flame every 10°, beginning at 430° F.

Samples representing rejected material will be retained in the test bureau not longer than two weeks from date of test. If at the end of that period the sellers have not given shipping directions, the material represented will be returned to them at their risk, they paying the freight both ways, in either case.

Cylinder Stock.—(Philadelphia & Reading Railway, Office First Vice-President, Philadelphia, Pa., Nov. 15, 1893.) This grade of oil shall have a flashing point not below 525° F., and a burning point not below 600° F. The test will be made in an open vessel

by heating the oil not less than 20° per minute, and applying the test flame every 7° beginning at 504°.

The oil must flow readily at 60° F., and at 350° F. must show a viscosity not lower than that of a pure cane sugar solution containing 52 grams of sugar in 100 cc. of the syrup, the viscosity of the sugar solution being taken at 80° F.

This oil must be transparent, with a reddish brown or green color, free from lumps or specks.

No oil will be accepted which shows more than 5 per cent. of flocculent or tarry matter settled out, after 5 cc. of the oil have been mixed with 95 cc. of 88° gasoline, and allowed to stand for one hour.

Cold Test.—About 2 ounces of oil is put in a 4-ounce sample bottle, a thermometer inserted and the oil frozen with a mixture of ice and salt. When the oil is hard the bottle is taken from the freezing mixture and the frozen oil stirred thoroughly with the thermometer until it will flow. The reading of the thermometer is then taken, and this temperature is regarded as the cold test of the oil.

NOTE.—The viscosity tests will be made upon the Torsion viscosimeter.

Cylinder Oil.—(Philadelphia & Reading Railway, Nov. 15, 1893.) This oil shall consist of a high grade cylinder stock, compounded with not less than 20 per cent. by weight of acidless animal oil, tallow or tallow oil being preferred.

(The other tests specified for this "compounded oil" are exactly as given for cylinder stock just above.)

CHAPTER XXI.

SPECIFICATIONS FOR SPECIAL ENGINE AND MACHINE OILS AND CAR OILS.

A. WAR DEPARTMENT SPECIFICATIONS.

(Office Depot Quartermaster, New York City.)

Gas Engine Cylinder Oil (Non-Carbonizing).—(Mar. 1, 1909.) This oil is suitable for lubrication of gasoline engines used in emplacements and with search lights.

Must be a pure filtered mineral oil. Must be free from acid, alkali and suspended matter, and pass satisfactorily the following tests:

Specific Gravity.—Must be not less than 0.909 nor more than 0.918 at 60° F. [22.5° to 24.0° Bé.]

Flash.—Must not flash below 410° F.

Fire.—Must not burn below 450° F.

Cold Test.—Must flow at a temperature of 16° F.

Viscosity.—Must not be less than 5.65 at 50° C. (Engler.) [About 212 Saybolt at 122° F.]

Acid.—Must not give an acid reaction on polished copper in 24 hours.

Alkali.—Ash must not show an alkaline reaction.

Water.—Must not froth nor bump when heated in flash cup.

Saponification.—Must be unaffected by an alcoholic solution of caustic potash.

Quart samples must be submitted with bid.

Engine Oil, "Kero."—(Jan. 2, 1908.) This oil is suitable for use in cylinders of kerosene engines.

Must be a compounded oil composed of 25 per cent. of fixed oil of good quality, and 75 per cent. pure filtered mineral oil. Must be free from acid, alkali and suspended matter, and satisfactorily pass the following tests.

Specific Gravity.—Must not be less than 0.844 nor more than 0.888 at 60° F. [27.6° to 35.9 Bé.]

Flash.—Must not flash below 395° F.

Fire.—Must not burn below 430° F.

Viscosity.—Must not be less than 4.06 at 50° C. (Engler.) [About 151 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 30° F.

Alkali.—Ash must not show an alkaline reaction.

Water.—Must not froth nor bump when heated in flash cup.

Saponification.—When oil is treated with alcoholic caustic potash must show the presence of 25 per cent. fixed oil.

Quart samples must be submitted with bid.

Engine Oil, High Speed.—(Jan. 2, 1908.) This oil is suitable for lubrication of high speed engines, dynamos and high speed work generally.

Must be a pure filtered mineral oil. Must be free from acid, alkali and suspended matter, and pass satisfactorily the following tests:

Specific Gravity.—Must not be less than 0.869 nor more than 0.873 at 60° F. [30.4° to 31.1° Bé.]

Flash.—Must not flash below 375° F.

Fire.—Must not burn below 420° F.

Viscosity.—Must not be less than 2.40 at 50° C. (Engler.) [About 85 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 5° F.

(Other tests as for gas engine cylinder oil above.)

Machine Oil, Light.—(Jan. 2, 1908.) This oil is suitable for shafting and ordinary lubrication duties on light running machinery.

Must be a pure filtered mineral oil. Must be free from acid, alkali and suspended matter, and pass satisfactorily the following tests:

Specific Gravity.—Must not be less than 0.900 nor more than 0.909 at 60° F. [24° to 25.5° Bé.]

Flash.—Must not flash below 370° F.

Fire.—Must not burn below 420° F.

Viscosity.—Must not be less than 2.38 at 50° C. (Engler.) [About 84 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 30° F.

(Other tests as for gas engine cylinder oil above.)

Machine Oil, Heavy.—(Jan. 2, 1908.) This oil is suitable for ordinary machinery where heavy pressure and slow speed call for an oil of heavier body than Machine Oil, Light. Also for engine bearings of moderate speed and pressure.

Must be a pure filtered mineral oil. Must be free from acid, alkali and suspended matter, and pass satisfactorily the following tests:

Specific Gravity.—Must not be less than 0.881 nor more than 0.886 at 60° F. [28° to 29° Bé.]

Flash.—Must not flash below 380° F.

Fire.—Must not burn below 440° F.

Viscosity.—Must not be less than 4.50 at 50° C. (Engler.) [About 168 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 32° F.

(Other tests as for gas engine cylinder oil above.)

Marine Engine Oil.—(Jan. 2, 1908.) This oil is suitable for general lubrication of marine engines. All work except cylinder.

Must have a compounded oil composed of 20 per cent. blown rapeseed oil and 80 per cent. pure mineral oil. Must be free from mineral acid, alkali, and suspended matter, and must satisfactorily pass the following tests:

Specific Gravity.—Must not be below 0.920 nor above 0.926 at 60° F. [21.2° to 22.2° Bé.]

Flash.—Must not flash below 410° F.

Fire.—Must not burn below 470° F.

Viscosity.—Must not be below 8.11 at 50° C. (Engler.) [About 304 Saybolt at 122° F.]

Cold Test.—Must flow at a temperature of 35° F.

Saponification.—When oil is treated with alcoholic potash must show the presence of 20 per cent. blown rapeseed oil.

(Other tests as for gas engine cylinder oil above.)

B. PENNSYLVANIA RAILROAD SPECIFICATIONS.

(Motive Power Dept., Altoona, Pa., Mar. 30, 1915.) (General specifications omitted.)

Paraffin and Neutral Oils.—These grades of oil will not be accepted if the sample from shipment:

Is so dark in color that printing from long primer type cannot be read with ordinary daylight through a layer of the oil ½ inch thick.

Flashes below 298° F.

Has a gravity at 60° F., below 24° or above 35° Bé.

From Oct. 1 to May 1 has a cold test above 10° F., and from May 1 to October 1 has a cold test above 32° F.

The color test is made by having a layer of the oil of the prescribed thickness in a proper vessel, and then putting the printing on one side of the vessel and reading it through the layer of oil with the back of the observer toward the source of light.

Well Oil.—This grade of oil will not be accepted if the sample from shipment:

Flashes, from May 1 to Oct. 1 below 298° F., or from Oct. 1 to May 1, below 249° F.

Has a gravity at 60° F., below 28° or above 31° Bé.

From Oct. 1 to May 1, has a cold test above 10° F., and from May 1 to Oct. 1, has a cold test above 32° F.

Shows any precipitation when 5 cc. are mixed with 95 cc. of gasoline.

The precipitation test is to exclude tarry and suspended matter. It is made by putting 95 cc. of 88° Bé. gasoline, which must not be above 80° F. in temperature, into a 100 cc. graduate, then adding the prescribed amount of oil and shaking thoroughly. Allow to stand 10 minutes. With satisfactory oil no separated or precipitated material can be seen.

530° Flash Test Oil.—This grade of oil will not be accepted if the sample from shipment:

Flashes below 522° F.

Has a gravity at 60° F., below 25° Bé.

Shows precipitation with gasoline when tested as described for well oil.

Shippers must pay freight both ways on rejected material.

CHAPTER XXII.

SPECIFICATIONS FOR CUTTING OILS.

Cutting Compound, Paste.—(Navy Dept., Bureau of Supplies and Accounts, Washington, D. C., Jan. 2, 1917.) To be used for machine cutting tool lubricant when mixed as directed.

To be a soluble paste compound consisting of an alkali soap, mineral oil and fixed saponifiable oils and water. To be free from disagreeable odors, mineral acids, or any ingredients injurious to persons handling the material.

To contain not more than 25 per cent. of water, not more than 20 per cent. of alkali soap, not less than 40 per cent. of mineral oil, and the remainder fixed saponifiable oil. It must form a stable emulsion when mixed with water.

The emulsion must sufficiently lubricate turret and automatic machines to prevent sticking, the solution used to be suitable for work being performed on the machine, and must show no tendency to leave a gummy residue.

Strips of polished steel are to show no appreciable corrosion after being partly immersed in mixture for a period of two weeks.

One pound of the paste will be put into emulsification with 3 gallons of water and the emulsion permitted to flow at the rate of 1 gallon per minute over a steel cylinder heated by an electric coil consuming 440 watts which maintains a constant temperature of 100° C. in air. After a period of 8 hours, the maximum rise of temperature of the emulsion shall not exceed 12° C. This physical test will be conducted at the New York Navy Yard on samples before approval on the standard apparatus shown in drawing No. 36367-A, which may be obtained from the Engineer Officer at the Navy Yard, New York.

To be purchased by the pound and delivered in heavy barrels of not more than 500 pounds capacity, suitable for foreign shipment, or in 25-pound friction-top cans packed in wood cases, two to a case. The quality of the containers to be such as to provide against leakage or deterioration in storage and in handling.

Contractors who propose to furnish cutting compound (paste)

under these specifications may have a 5-pound sample tested at Navy Yard, New York, and if the test proves satisfactory this cutting compound (paste), will be placed on an acceptable list. The contractor will be required to submit a 5-pound sample of cutting compound (paste) to be supplied with each new bid, and state the approximate date of test.

Soluble Cutting Oils or Cutting Compounds (Liquid Form).—(Navy Dept., Mar. 1, 1916.) To be used in emulsion with water for machine cutting-tool lubricant.

To be a clean and homogeneous mixture of soluble alkali soap in mineral and fixed saponifiable oils. It shall be free from disagreeable odors, sediment, mineral acids, ingredients injurious to persons handling, and shall contain not more than 10 per cent. of water and not more than 20 per cent. of soluble alkali soap.

To be capable of readily mixing with water in all proportions, without the use of sodium carbonate or other addition, to form a stable emulsion.

The emulsified oil must sufficiently lubricate turret and automatic machines to prevent sticking, the solution used to be suitable for the work performed on the machine, and must show no tendency to leave a gummy residue.

Strips of polished steel are to show no appreciable corrosion after being partly immersed in the emulsion for a period of two weeks.

(Three pints of oil are put into emulsification with 3 gallons of water, and subjected to the cooling test as given for the cutting paste above. The methods of packing, etc., are substantially as there described, payment being by the gallon.)

Mineral Lard Oil.—(Navy Dept., Feb. 1, 1916.) To be used for machine cutting tool lubricant, either unadulterated or compounded with mineral oil or soda and water.

To be clean and homogeneous; free of disagreeable odors, rancidness, sediment, or ingredients injurious to persons handling the material; and to be easily soluble and retain oily consistency in kerosene or soda and cold water mixtures. To have a specific gravity at 15° C. of about 0.90, a flash point in an open tester

of not less than 180° C., and flow at —4° C. To contain not less than 25 per cent. and not more than 35 per cent. of fixed saponifiable oils, from 60 to 70 per cent. of mineral, and not more than 5 per cent. of free fatty acid (calculated as oleic acid).

Measured in a Saybolt viscosimeter (with a 30-second water rate at 15° C.) the oil to show about 185 seconds at 38° C. and 115 seconds at 48° C.

A saucer with enough test oil to cover the bottom when placed in an oven at a constant temperature of 120° C. for a period of 8 hours, when taken out and permitted to cool gradually, shall show no signs of a gummy residue.

Strips of polished steel to show no appreciable corrosion in two weeks' time when partly immersed in samples of the oil, or in a mixture of the oil and kerosene, or in an emulsion of the oil, soda and water.

(Three gallons of the unadulterated oil will be put into a steel tank and given the cooling test described under cutting paste above, the maximum rise of temperature permitted in 3 hours being 30° C. Delivery in packages as above described; payment by the gallon.)

Lard Oil.—For pipe cutting and threading purposes. (Navy Dept., Oct. 1, 1915.) See page 160.

Lard Oil.—(Seaboard Air Line Railway, July 7, 1915.) No. 2 for turret lathes, cutting threads, staybolt cutters, etc. (See page 163.)

Screw Cutting Oil.—(Philadelphia & Reading Railway, Nov. 15, 1893.) This oil shall consist of paraffin oil of about 27° Bé. gravity, compounded with not less than 25 per cent. by weight of fat oil, cottonseed preferred.

The compounded oil shall show a flashing point not below 300° F., and a burning point not above 425° F. The test will be made in an open vessel by heating the oil not less than 15° per minute, and applying the test flame once in 7°, beginning at 275°.

From Oct. 1 to Apr. 1 the oil must have a cold test not above 15° F.

CHAPTER XXIII.

SPECIFICATIONS FOR GREASES, GRAPHITE, BOILER COMPOUND AND COTTON WASTE.

(Navy Dept., Bureau of Supplies and Accounts, Washington, D. C.)

Mineral Lubricating Grease.—(Nov. 1, 1916.) Mineral lubricating grease shall be a homogeneous mixture consisting exclusively of from 80 to 90 per cent. of mineral oil and the remainder an odorless lime soap made from clear animal fats and the proper amount of lime for saponification. It shall be free from fillers, uncombined lime, gritty substances, rosin oil, rosin, or resinates, and from mineral or fatty acids, alkalies, or any deleterious impurities, and shall not yield more than 2 per cent. of ash from medium grease, and not more than 3 per cent. of ash from hard grease. The grease shall lose not more than 2 per cent. of its weight when heated for 1 hour at 110° C. in a glass crystallizing dish containing 10 grams of grease, in an air oven.

(*a*) Medium grease shall flow at a temperature of from 75° to 80° C. when tested in a glass crystallizing dish containing about 10 grams of grease, heated in an air oven.

(*b*) Hard grease shall flow at a temperature of about 90° C. when tested in a glass crystallizing dish containing about 10 grams of grease, heated in an air oven.

The grease shall possess lubricating properties determined by practical test in a lubricant-testing machine, as follows:

When fed at a rate of not exceeding 1½ grains per minute through a grease cup, on friction surface of a brass shoe having 9 square inches bearing surface, sustaining a load of 1,926 pounds against a steel journal 6 inches in diameter, revolving at a surface velocity of 405 feet per minute, it shall maintain an even temperature of not more than 50° C. above surrounding normal temperatures, and the coefficient of friction shall be constant during the last hour of the run and shall not exceed 0.013.

Mineral lubricating grease is intended for use in compression grease cups for bearings. For rapid-running machines in cool

climates medium grease should be ordered. For hot climates or heavy-running machinery hard greases should in general be ordered.

The grease shall be delivered in friction-top cans of 10 pounds' capacity, properly labeled with name and grade of material, manufacturer's name, and net contents of can. To be packed in boxes of 80 or 100 pounds each; the boxes to be made of 7/8-inch new pine or spruce, planed on both sides, and properly labeled with contents and contract number.

Graphite Lubricating Grease.—(Nov. 1, 1916.) Graphite grease to consist of 8 to 10 per cent. of amorphous graphite containing at least 82 per cent. of graphitic carbon mixed with a mineral lubricating grease of the following composition and consistency: Mineral grease to be a homogeneous mixture consisting of from 80 to 90 per cent. mineral oil, and the remainder an odorless lime soap made from clean animal fats and the proper amount of lime for saponification. To be free from grit, rosin, or resinates, and from mineral or fatty acids, alkalies, or any deleterious impurities. Medium grease to flow at a temperature of from 75° to 80° C., and hard grease to flow at about 90° C. when tested in a glass crystallizing dish containing about 10 grams of grease, heated in an air oven. The grease to lose not more than 2 per cent of its weight when heated for one hour at 110° C. and tested in a similar dish and oven.

To possess lubricating properties, determined by practical test in Riehle bearing testing machine, as follows: (Method exactly as for "mineral lubricating grease" just above, except that grease fed at a rate not exceeding 2½ grains per minute and the coefficient of friction "shall not exceed 0.031 for medium grease and 0.04 for hard grease.")

Graphite lubricating grease under these specifications is intended for use on gearing of heavy machinery and bearings exposed to weather and heat. If harder grease is required for special purposes, a larger percentage of graphite may be specified or graphite will be added to the grease supplied.

(Specifications for packing as given above.)

Flake Lubricating Graphite.—(May 1, 1914.) To be the best grade of foliated flake graphite reasonably free from amorphous graphite. Samples taken from any lot must show on analysis at least 88 per cent. of graphitic carbon. It must be free from grit, dirt, or other deleterious substance. Requisition to show whether coarse, medium, or fine graphite is desired.

Flake lubricating graphite must be put up in air-tight rectangular cans with screwed tops, each containing 25 pounds, or as may be otherwise required.

Each can must be marked with the name of the material, the trade-mark, if any, and the name of the manufacturer.

Graphite, Ground, Amorphous (Lubricating).—(Jan. 2, 1917.) Samples taken from any lot must show upon analysis at least 82 per cent. of graphitic carbon. It must be free from grit, dirt, or any other deleterious substance.

Amorphous graphite must be ground fine enough to pass a No. 20 bolting cloth.

To be put up in strong well-made 100-pound barrels, with marking on heads, or, if directed, in 5- and 25-pound commercial tins.

Each container must be marked with the name of the material, the trade-mark, if any, and the name of the manufacturer.

Boiler Compound.—(Sept. 2, 1913.) To be a powdered compound composed of sodium carbonate, trisodium phosphate, starch, and cutch.

These materials are to be intimately united by thorough digestion, dried and finely powdered, the product to be readily soluble in water and uniform in composition.

The compound must show on analysis at least 76 per cent. of anhydrous sodium carbonate (Na_2CO_3), 10 per cent. of trisodium phosphate ($Na_3PO_4 . 12H_2O$), 1 per cent. of starch, and sufficient cutch to yield 2 per cent. of tannic acid. The remainder to consist of water and only such impurities as are common to the ingredients.

To determine the sodium carbonate, incinerate 1 gram, dissolve in water, and wash into a flask. Add an excess of standard

acid, boil, and titrate back with standard alkali, using phenolphthalein as indicator. Calculate to Na_2CO_3, which result is the actual sodium carbonate plus the sodium carbonate equivalent of the alkalinity of the trisodium phosphate. Therefore, deduct from this figure 14/100 of the percentage of fully hydrated trisodium phosphate found present, and the result is the percentage of sodium carbonate.

The contractor shall submit an affidavit sample of the cutch used in the manufacture of each lot of material delivered.

To be packed in practically air-tight tins, of the soldered-top type, each tin to contain 25 pounds net of the powdered compound. To be delivered in substantial wooden crates, 4 tins to the crate.

Each tin to be marked with name and net weight of contents. Each crate to have the name of the material, quantity contained, and name of manufacturer neatly stenciled on one end.

Net weight only will be paid for.

Cotton Waste.—(June 1, 1914.) Standard white cotton waste only will be purchased as the needs of the service require. A sample of cotton waste showing the minimum quality of cotton waste acceptable can be obtained upon application to the general storekeeper of the New York Navy Yard.

If practicable, the inspection will be made at the mill during the process of manufacture and baling. Inspection upon delivery will be made where it is impracticable to inspect at the mill and when the waste is baled. All handling of material necessary for purposes of inspection shall be performed and all test specimens necessary for the determination of the qualities of the material used shall be prepared and tested at the expense of the contractor.

The waste will be supplied in bales, net weight to be 50 or 100 pounds, as specified, such bales having a volume of 3½ cubic feet and 7 cubic feet, respectively. The bales supplied must average the weight that is ordered, a variation of 10 per cent. in the weight of single bales being allowed.

Gross weight will be paid for, subject to the following provisions, *viz.:* Weight of wrappings, including hoops, not to exceed 6 per cent. of gross weight, and moisture not to exceed 3

per cent. Any excess of the foregoing elements up to 3 per cent. will be deducted from contract price at the same price per pound that is paid for the waste. If the tare exceeds 9 per cent. or moisture 6 per cent., the waste will not be accepted.

The material desired under these specifications is to be all new fine, white, soft, cotton threads, of about 10 per cent. slasher, 15 per cent. spooler, and the balance of cop, properly mixed with longer threads to form a binder, and machined into a homogeneous mass. The waste shall be practically free from threads less than 3 inches long, and shall not contain any colored threads, any coarse or unabsorbent threads, strings, and fiber (except cotton), sweepings, flyings, dirt, or material that has been soiled or washed.

CHAPTER XXIV.

SPECIFICATIONS FOR BURNING OILS.

Mineral Sperm Oil.—(Navy Dept., Bureau of Supplies and Accounts, Washington, D. C., June 15, 1910.) Must be prime white or better and free from all cloudiness, impurities or adulterations; must not become cloudy at any temperature above 32° F., must be entirely free from acid; must not flash below 255° F. (open tester), 300° F. fire test, and have a specific gravity between 37° and 41° Bé. (0.8383 to 0.8187) at 60° F.; Lima oil products excluded; to be purchased and inspected by weight.

(*a*) Before acceptance the oil will be inspected. Samples of each lot will be taken at random, the samples well mixed in a clean vessel, and the sample for test taken from this mixture. Should the mixture be found to contain any impurities or adulterations, the whole delivery of oil it represents will be rejected and is to be removed by the contractor at his own expense.

(*b*) The quantity to be delivered to be determined by weight; the number of pounds per gallon to be determined by the specific gravity of the oil at 60° F. multiplied by 8.33 pounds, the weight of a gallon (231 cubic inches) of distilled water at the same temperature.

(*c*) To be delivered in specified cans and cases or in white oak casks.

NOTE.—Oil deliveries, except final deliveries, shall be in lots of not less than 5,000 pounds, each delivery will be inspected and tested as a separate lot, if rejected bought in open market for contractor's account.

Mineral Sperm Oil.—(War Dept., Office Depot Quartermaster, New York City, Feb. 20, 1908.) Must be clear, neutral and water white, and must conform to the following tests:

Specific Gravity.—39°-41° Bé. at 60° F.
Flash.—Must not flash below 255° F.
Fire.—Must not burn below 300° F.
Cloudiness.—Must not become cloudy above 32° F.

Kerosene.—(Navy Dept., May 1, 1914.) A representative sample to be tested photometrically after burning for one hour in a lamp fitted with a No. 1 Sun Hinge burner. Five hours later another photometric test shall be made to determine any change in intensity of the light, the maximum allowable loss being 5 per cent. The flame shall show at least 6 candle-power when compared photometrically with an incandescent lamp which has been standardized by the Bureau of Standards.

The sample must show a flash test of not less than 115° F. and a fire test of not less than 140° F. These tests shall be conducted in a "Tagliabue" closed type tester.

A part of sample shall be shaken with warm water and allowed to cool and separate. The water when separated, to react neutrally to methyl orange.

For eastern oil the specific gravity at 60° F. is required to be not greater than 0.802; for western oil not greater than 0.813.

When burned in a standard lamp or lantern, the oil shall burn steadily and clearly, without smoking and with a minimum incrustation of the wick, for a period of 72 hours.

The quantity delivered shall be determined by weight. (Detailed methods of weighing and packing in specified containers also given.)

Petroleum Burning Oil.—(Baltimore & Ohio Railroad, Motive Power Dept., Feb. 25, 1911.) (General specifications are given under B. & O. cylinder oil No. 3. See Index.) Two kinds of petroleum burning oil will be used, known as 150° fire test for general use, and 300° fire test for use in passenger cars.

150° Fire Test Oil, for headlights, office, switch and station lamps.

(*a*) It must have a flash test of at least 125° F. Tagliabue open cup.
(*b*) It must have a fire test not below 150° F.
(*c*) It must have a cloud test not above 0° F.
(*d*) It must be "water white" in color, and free from sulphur in any form.
(*e*) Its gravity must be between 45° and 48° Bé. at 60° F.

(*f*) It must show no flock when heated to a temperature of 270° F. for one hour.
(*g*) Weight per gallon, 6.61 pounds.
(*h*) It must burn freely and steadily with the standard burners and wicks used for this oil. Using a banner burner with 1-inch flat wick, the oil must give a good flame for 24 hours, without smoking or forming ears, and giving only a slight stain on chimney. Using a standard long time burner with ¼-inch round wick, and 12 ounces of oil, all the oil must be consumed, giving a good flame the entire time. In either burning test the wick must not be trimmed, or raised during the test.

300° Fire Test Oil, for lamps in passenger cars.

(*a*) It must have flash test not below 250° F.
(*b*) It must have a fire test not below 300° F.
(*c*) It must have a cloud test not above 32° F.
(*d*) It must be "standard white" in color, and free from sulphur in any form.
(*e*) Its gravity must be between 38° and 42° Bé. at 60° F.
(*f*) It must show no flock when heated to 450° F.
(*g*) Weight per gallon, 6.85 pounds.
(*h*) It must burn freely and steadily with the standard burners and wicks used for this oil.

Method of Making Tests.—The "Open Tagliabue" cup is used for determining the flashing and burning point of 150° fire test oil; heating at the rate of 2° F. per minute, and applying the test flame every degree from 120° for flash, and every 4° after flash for the burning point.

The "Cleveland" cup is used for determining the flashing and burning point of 300° Fire Test oil, heating at the rate of 5° per minute, and applying the test flame every 5° from 230° F.

The Cloud Test is made as follows: Two ounces of oil are placed in a 4-ounce sample bottle, with a thermometer suspended in the oil. The bottle is exposed to a freezing mixture of ice and salt, and the oil stirred with a thermometer while cooling.

The temperature at which the cloud forms is taken as the cloud test.

The flock test is made by having about 2 fluid ounces of the oil in a 6-ounce beaker, with a thermometer suspended in the oil, and then heating slowly until the thermometer shows the required temperature. The oil changes color, but must show no precipitation.

In addition to the above tests the Baltimore & Ohio Railroad Company reserves the right to make any additional tests to insure that only material meeting all the requirements set forth in this specification be accepted, and all material represented found not up to any one or all the requirements, will be rejected.

Burning Oils.—(Norfolk & Western Railway, Motive Power Dept., Roanoke, Va., June 11, 1909.) Two grades of petroleum burning oils will be used. The material desired under these specifications is pure petroleum distillate, unmixed with any other substance, and must conform to the following specifications:

Long Time Burning Oil.—This grade of oil will not be accepted which:

1. Flashes below 120° F.
2. Burns below 140° F.
3. Is not water white in color.
4. Is cloudy from any cause whatsoever.
5. Becomes opaque when reduced to the temperature of from 0° to —5° F., and allowed to stand at this temperature for 10 minutes.
6. Has a gravity below 45° or above 50° Bé. at 60° F.
7. Does not comply satisfactorily with the following burning conditions: Norfolk & Western Railway type semaphore signal lamp thoroughly cleaned is fitted with an Armspear "long time slip burner," 3⅛-inch shaft, and a new red wool long time burning wick; 600 cc. of oil are delivered into the oil pot, the lamp lighted, and the wick turned up to give a flame 1 inch high without smoking. A second lamp is fitted up in like manner and lighted at the same time. After both

lamps have burned for one hour the second lamp is extinguished. After the first lamp has burned for 120 hours, the second lamp is relighted and the height of the two flames compared. The flame from the first lamp must show a height of flame at least one-half that of the comparison flame. The first lamp must then continue to burn without marked diminution of flame until all the oil in the oil pot is consumed, which total burning period must be at least 150 hours.

The flashing and burning points of this oil will be determined by using the Tagliabue open fire tester. (Method specified for flash test, fire test and cold test.)

300° Burning Oil. This grade of oil will not be accepted which:

1. Flashes below 250° F.
2. Burns below 300° F.
3. Is not water white or prime white in color.
4. Is cloudy from any cause whatever.
5. Becomes opaque when reduced to a temperature of 32° F.
6. Shows precipitation or discoloration deeper than a dark straw when heated to 400° F. and allowed to cool to the temperature of the room.
7. Has a gravity below 37° or above 41° Bé. at 60° F.
8. Does not burn up completely 600 cc. of oil from a lamp fitted with Dual Burner No. 3, and two duplex wicks, without encrusting the wick and without any marked diminution of the flame. (Methods specified for flash, fire, and heating tests. Flash and fire tests are with a porcelain dish in a sand bath.)

Specifications for Petroleum Products.—(Pennsylvania Railroad, Office General Superintendent of Motive Power, Altoona, Pa., Mar. 30, 1915.) (General specifications omitted.)

150° Fire Test Oil.—This grade of oil will not be accepted if sample from shipment:

1. Is not "water white" in color.
2. Flashes below 130° F.
3. Burns below 151° F.
4. Is cloudy or shipment has cloudy barrels when received, from the presence of glue or suspended matter.
5. Becomes opaque or shows cloud when the sample has been 10 minutes at a temperature of 0° F.
6. Fails to give a satisfactory flame during six days continuous burning in a long time burning switch lamp, or shows an appreciable amount of hard compact crust on the wick at the end of the test.

The examination of a shipment for oil that is cloudy from glue or suspended matter, must be made by those by whom the oil is received. This examination applies especially to 150° and 300° fire test oils. As this defect rarely characterizes all of the barrels of a shipment, it is obvious that the sample for test may fail to show it. Accordingly when any barrel or barrels in a shipment are found to be cloudy from glue or suspended matter, such barrels must be set aside and returned to the shippers, notwithstanding the test report has shown the shipment to be ready for use.

300° Fire Test Oil.—This grade of oil will not be accepted if sample from shipment:

1. Is not "water white" in color.
2. Flashes below 249° F.
3. Burns below 298° F.
4. Is cloudy or shipments have cloudy barrels when received, from the presence of glue or suspended matter.
5. Becomes opaque or shows cloud when the sample has been 10 minutes at a temperature of 32° F.
6. Shows precipitation when some of the sample is heated to 450° F.

The precipitation test is made by having about 2 fluid ounces of the oil in a 6-ounce beaker, with a thermometer suspended in the oil, and then heating slowly until the thermometer shows the

required temperature. The oil changes color but shows no precipitation.

Petroleum Products.—(Seaboard Air Line Railway, Motive Power Dept., July 19, 1915.) The materials desired under this specification are petroleum or the products of its distillation and refining, unmixed with any other substance and conforming to the detailed specifications below:

Illuminating oils must be water white in color, and free from sulphur in any form. "Cracked" oils are not desired. Products having an offensive odor or containing any admixture of other oils, will not be accepted. All samples must show a neutral or slightly alkaline reaction.

One sample shall be taken from each carload or fraction thereof, and subjected to the following tests:

Headlight or 150° Oil.—Sample must not flash below a temperature of 130°, or burn below a temperature of 150° F., when heated at the rate of 2° per minute. The test flame to be applied once every 5°, beginning at 110°. The above flash and fire tests will be made in the Tagliabue open-cup tester.

Samples must remain clear and transparent when cooled to a temperature of 0° and held there for 10 minutes.

It must have a specific gravity of between 41° and 48° Bé.

Mineral Seal or 300° Oil.—Sample must not flash below a temperature of 245°, or burn below a temperature of 300° F., when heated at the rate of 5° per minute. The test flame to be applied once every 5°, beginning at 180°. The above flash and fire tests will be made in the Tagliabue open-cup tester.

Samples must remain clear and transparent when cooled to a temperature of 32° F., and held there for 10 minutes.

It must have a specific gravity of between 33½ and 43° Bé.

CHAPTER XXV.

SPECIFICATIONS FOR GASOLINE AND FUEL OIL.

Gasoline.—(Navy Dept., Oct. 1, 1913.) Gasoline to be of a high grade, refined, and free from all impurities. No natural gas gasolines will be accepted, nor will they be mixed with any gasoline submitted for acceptance.

Before acceptance the gasoline will be inspected. Samples of each lot will be taken at random; these samples will be well mixed in a clean closed vessel, and a sample for test taken from this mixture.

One hundred cc. will be taken as a test sample. This amount will be distilled in an Engler apparatus at a rate of not less than 10 cc. per minute.

Boiling point must not be lower than 130° F.
Fifty per cent. of the sample must distill below 275° F.
Ninety-five per cent., if called for, must distill below 340° F.
One hundred per cent. must distill below 360° F.
Not less than 98 per cent. of the liquid will be recovered from the distillation.

Five cc. of the sample, when poured over a sheet of white paper, shall evaporate completely without leaving any stain.

The apparatus used for distillation and method of conducting the test shall be as follows: The apparatus shall consist of a 4-ounce Engler flask with outlet high on neck. The top of the thermometer shall be opposite the bottom of the outlet tube. The condenser shall be a standard 20-inch Liebig type of condenser. The boiling point will be the temperature shown by the thermometer when the first drop of the condensed liquid falls from the end of the condenser into the receiving flask. The distillation shall be pushed to completion, at which time the bottom of the flask shall be dry. The end point at this time will indicate by a small flash or puff of smoke.

(Details also given for weighing, for containers, etc.)

Light Petroleum Products for All Uses.—(Norfolk & Western Railway, Motive Power Dept., Roanoke, Va., Mar. 2, 1912.) The materials covered by this specification are as follows:

88° gasoline.
Deodorized gasoline for gas engine use.
Deodorized naphtha or benzine.

88° Gasoline.—This material to be a high-grade, refined and deodorized gasoline, free from all impurities.

A sample will be taken from a single drum of a shipment and subjected to test. Failure to conform to the following requirements will be cause for rejection.

Distillation test, Engler apparatus:

	Per cent.	°F.
Boiling point (first drop)		90 to 100
Rate of distillation	10	90 to 110
	50	125 to 130
	80	165 to 170
	100	190 to 195

Evaporation Test. 25 cc. will be measured into a weighed thin glass beaker, the beaker immersed in hot water, and allowed to remain until complete evaporation of the gasoline has taken place. An increase in weight of the beaker after this operation in excess of 1 milligram will not be allowed.

This material to be purchased by the gallon and to be shipped in steel drums of approximately 55- or 110- gallon capacity, the drums to conform to all requirements specified by the Bureau for the safe transportation of explosives and inflammable liquids, and said drums shall remain the property of the shipper.

Deodorized Gasoline for Gas Engine Use.—This material to be a high grade, refined and deodorized gasoline, free from all impurities.

A ½-gallon sample will be drawn from a shipment and subjected to test. Failure to conform to the following requirements will be cause for rejection.

Distillation test, Engler apparatus:

	Per cent.	°F.
Boiling point (first drop)	—	above 130
Rate of distillation	50	below 240
	100	below 320
	98	to be recovered

Test for presence of heavy non-volatile oils; 25 cc. will be evaporated to a bulk of approximately 5 cc., and this when poured over a sheet of white paper shall evaporate completely without leaving a stain.

While the gravity for this material is not a requirement, preference in placing orders will be given to materials having a gravity between 58° and 62° Bé. at 60° F.

In entering bids for this material parties shall submit with their price the specific gravity of the product they propose furnishing, which gravity shall be maintained by them with an allowable variation of 2° Bé. Failure to conform to this requirement will be a cause for proper deductions from the charges made.

This material to be purchased by the gallon and shipment to be made in tank cars, unless otherwise stated with the order.

Deodorized Naphtha or Benzine.—This material to be a high grade refined and deodorized naphtha, free from all impurities.

A sample will be taken from a single barrel of a shipment and subjected to test. Failure to conform to the following requirements will be cause for rejection.

Distillation test, Engler apparatus:

	Per cent.	°F.
Boiling point (first drop)		above 180
Rate of distillation	10	180 to 260
	50	285 to 290
	95	below 350
	98	to be recovered

Test for the presence of heavy non-volatile oils (as above).

This material to be purchased by the gallon, and to be shipped in wooden barrels of strong and tight construction, having a

capacity of about 50 gallons. Barrels to become the property of the N. & W. Railway Co.

The apparatus used for the distillation test(s) and the method of conducting same shall be as follows: The apparatus consists of an 8-ounce Engler flask, with outlet tube set in at an angle of 75° to the neck and approximately mid-way on same. The approximate dimensions of the flask are as follows:

Diameter of bulb	7.5 centimeters
Diameter of neck	2.0 centimeters

The outlet tube will be approximately 15 centimeters from bottom of flask. The thermometer used will be a 400° F., long bulb accurately standardized type, readings in 2°. The top of the thermometer bulb shall be opposite the bottom of the outlet tube in making distillations. The condenser shall be an ordinary 20-inch Liebig type; 100 cc. will be taken for a determination. The rate of distillation will be approximately 10 cc. (10 per cent.) per minute for the first eight portions of 10 cc. The boiling point will be the temperature shown when the first drop of the condensed liquid falls into the receiving cylinder. An ordinary 100 cc. graduate will be used as receiving cylinder. The end point in the distillation will be indicated by a small flash or puff of smoke.

The company reserves the right to make any further tests that in their judgment are necessary to insure to them that the materials are desirable under this specification.

All materials covered by this specification will be inspected and tested at destination.

Samples representing rejected material will be retained in the chemical department and same will be furnished shippers upon their request. Rejected material will be held for 15 days subject to disposition and at the risk of the shippers. If, at the end of this period, shippers have not advised return shipping directions, the material will be returned to them, they paying all freight charges both ways.

In all cases of rejection it shall be optional with the purchasing

agent of this company whether the order shall be cancelled or replacement allowed.

Petroleum Products.—(Seaboard Air Line Railway, Motive Power Dept., July 19, 1915.) The materials desired under this specification are petroleum or the products of its distillation and refining, unmixed with any other substance and conforming to the detailed specifications below:

Gasoline.—Gasoline should be water white in color. A sample sufficiently large to provide for the following tests, taken at random, will represent the shipment:

1. Gasoline must be of a specific gravity not less than 63° Bé.
2. A portion of the sample must be entirely volatile at a temperature not exceeding 100° F.
3. When blotting paper is moistened with a few drops of the sample, it must evaporate entirely, leaving no greasy stain.

Fuel Oil.—(Seaboard Air Line Railway, Motive Power Dept., Nov. 24, 1913.) This oil or "liquid fuel" is crude petroleum as received from the wells, or the product of crude petroleum, distilled or reduced. It must contain no sand or foreign matter in shape of sticks, waste, stones, etc., and must be sufficiently liquid to flow readily in 4-inch pipes at a temperature of 70° F.

It must contain as little water as possible, and oil containing more than 2 per cent. of water and other impurities will not be accepted.

Fuel oil will be paid for on a basis of volume at 60° F., also deducting all water contained, according to methods outlined as follows:

One sample will be taken from each carload or fraction thereof. The sampling of cars is to be made with car thief having valve at lower end. The thief with open valve will be lowered gradually into car and valve closed at instant of touching bottom. The thief thus filled will contain oil sample to be tested for water, sand and B. S. (Bottom Settlings).

Oil received in settling or storage tanks will be sampled with

Robinson or other standard thief, a sufficient number of samples being taken to secure an average of its contents.

Fuel oil will not be accepted for general use whose flash point is less than 110° F. when tested by the open cup, Tagliabue method. The oil to be heated at a rate of 5° per minute, and test flame applied every 5°, beginning at 90°.

The above flash point being the danger point at which the oil begins to give off inflammable gas, the fire or burning point is not required.

The test for water, sand and B. S. will be made as follows: 100 cc. of the sample will be placed in a 250 cc. graduated glass cylinder provided with stoppers, and thoroughly shaken up with not less than 150 cc. of gasoline. The mixture will be heated to 120° F., for from 3 to 6 hours to facilitate the separation of impurities, the amount of which can then be read from the graduations of the cylinder. All proportion of water and other impurities contained in the sample will be deducted from the volume contained in the car and not paid for.

The temperature of shipment will be tested directly as sample is removed from sampling tube, or by immersion of thermometer in the receptacle itself for not less than 1 minute. A deduction in volume for expansion at temperature of over 60° F. will be made at the rate of $^1/_{25}$ of 1 per cent. for each degree. At 90°, the deduction would be 1⅕ per cent., etc. Kansas and Oklahoma fuel oil furnished from Sugar Creek, or Kansas City, Mo., at 90° should have a deduction of 1¼ per cent.

Gravity of fuel oil should range between 13° and 29° Bé. at 60° F.

If any portion of an accepted shipment is subsequently found to be damaged, or otherwise inferior to the original sample, that portion will be returned to the shipper at his expense.

Any sample failing to meet all the requirements of this specification will be condemned, and this shipment represented by it will be returned to the manufacturer.

In cases of rejection the materials will be held for two weeks from the date of test. If by the end of that period the manufacturers have not given shipping directions, it will be returned to them at their risk, they paying the freight both ways.

Fuel Oil.—("Specifications for the Purchase of Fuel Oils for the Government with Directions for Sampling Oil and Natural Gas," Tech. Paper No. 3, Bureau of Mines, 1911.) General specifications for the purchase of fuel oil:

1. In determining the award of a contract, consideration will be given to the quality of the fuel offered by the bidders, as well as the price, and should it appear to be to the best interest of the Government to award a contract at a higher price than that named in the lowest bid or bids received, the contract will be so awarded.
2. Fuel oil should be either a natural homogeneous oil or a homogeneous residue from a natural oil; if the latter, all constituents having a low flash point should have been removed by distillation; it should not be composed of a light oil and a heavy residue mixed in such proportions as to give the density desired.
3. It should not have been distilled at a temperature high enough to burn it, nor at a temperature so high that flecks of carbonaceous matter began to separate.
4. It should not flash below 60° C. (140° F.) in a closed Abel-Pensky or Pensky-Martens tester.
5. Its specific gravity should range from 0.85 to 0.96 at 15° C. (59° F.); the oil should be rejected if its specific gravity is above 0.97 at that temperature.
6. It should be mobile, free from solid or semi-solid bodies, and should flow readily, at ordinary atmospheric temperatures and under a head of 1 foot of oil, through a 4-inch pipe 10 feet in length.
7. It should not congeal nor become too sluggish to flow at 0° C. (32° F.).

8. It should have a calorific value of not less than 10,000 calories per gram (18,000 British thermal units per pound): 10,250 calories to be the standard. A bonus is to be paid or a penalty deducted according to the method stated under Section 21, as the fuel oil delivered is above or below this standard.
9. It should be rejected if it contains more than 2 per cent. water.
10. It should be rejected if it contains more than 1 per cent. sulphur.
11. It should not contain more than a trace of sand, clay, or dirt.
12. Each bidder must submit an accurate statement regarding the fuel oil he proposes to furnish. (Details also given as to this statement, and in regard to sampling, deliveries and rejection.)

See also Tech. Paper No. 37, Bureau of Mines, by I. C. Allen, on "Heavy Oil as Fuel for Internal Combustion Engines."

Fuel Oil.—(United States Navy Specifications for the fiscal year, 1916-17, from page 584 of "Mineral Resources," Pt. II, U. S. Geol. Survey.)

(*a*) Fuel oil shall be a hydrocarbon oil of best quality, free from grit, acid, fibrous, or other foreign matter likely to clog or injure the burners or valves, and shall, if required by the Navy Department, be strained by being drawn through filters of wire gauze having 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe and strainers shall be in duplicate.

(*b*) The unit of quantity to be the barrel of 42 gallons of 231 cubic inches at a standard temperature of 60° F. For every decrease or increase of temperature of 10° F. (or proportion thereof) from the standard, 0.4 of 1 per cent. (or prorated percentage) shall be added or deducted from the measured or gaged quantity for correction.

(*c*) Flash point never under 150° F. as a minimum (Abel or Pensky-Marten's closed cup), or 175° F. (Tagliabue open cup), and not lower than the temperature at which the oil has a viscosity of 8 Engler (water = 1 Engler). (Example: If an oil has a viscosity of 8 Engler when heated to 186° F., then 186° F. is the minimum flash point at which this oil will be accepted.)

(*d*) Viscosity at 700° F. not greater than 200 Engler.

(*e*) Water and sediment not over 1 per cent. If in excess of 1 per cent., the excess to be subtracted from the volume, or the oil may be rejected.

NOTE.—If an Engler viscosimeter is not available, the Saybolt standard universal viscosimeter may be used, and 300 seconds Saybolt will be considered equivalent to 8 Engler, and 7,500 seconds Saybolt will be considered equivalent to 200 Engler.

The specification under (*c*) above is so drawn because it is considered inadvisable to heat oil above its flash point when burning it with mechanical atomization where the pressures run up to almost 300 pounds per square inch, and because it has been determined, by numerous experiments at the naval fuel-oil testing plant, that any clean oil may be efficiently burned if it is heated sufficiently to reduce its viscosity to 8 Engler.

CHAPTER XXVI.

GASOLINES.

The producers' idea of gasoline is "anything that can be burned in a gasoline engine." The increased use of automobiles, and of internal combustion engines generally, has resulted in such a demand for light petroleum distillates that production has been severely taxed. Domestic consumption and exports have increased without any corresponding increase in oil production. The distillates lighter than kerosene have ceased to be a cheap by-product for which an outlet is sought and has become one of the chief products of petroleum refining. Instead of running as much of the light distillate as possible into the burning oil (kerosene) as formerly practiced, the producers now incorporate as much of the light kerosene distillate in their gasoline as the present stage of automobile engine design will permit.

When the gasoline engine first became a commercial success, gasoline was usually rated at 70° Bé. or higher. As the demand for light distillates increased, the gravity was necessarily lowered, first to 65° Bé., then to 60° Bé., and finally (?) to 55° Bé. This change has been rendered necessary as the amount of the old type of gasoline could not supply the trade demand. Fortunately, the automobile engine has developed so that it can use these heavier distillates successfully, but the end is not yet, either in lowering of the gravity for motor fuels or in improved automobile engine design. The real solution of the problem is as much in the hands of the motor designer as in the hands of the gasoline producer.

In order to increase the output of motor fuels to meet the demand, several new types of gasoline have been developed.

Straight refinery gasoline, the old type of gasoline, is made by distilling off the light oils already existing in certain crude petroleums, notably Pennsylvania crudes, the product being distilled several times to remove the heavy oils or "tailings." The output of this grade has been greatly increased by including more of the light kerosene distillate as explained above.

"Cracked" gasoline, or synthetic gasoline, is made by a number of recently patented processes (such as the Burton and the Rittman processes). The heavy petroleum oils are exposed to very high temperatures, either in the liquid or the gaseous condition and under more or less pressure, so that the heavy oils decompose into oils of lower boiling points. The light oils formed by this decomposition or "cracking" are distilled off for motor fuels, the product being similar to straight refinery gasoline so far as boiling point, or power production is concerned. The cracked gasolines are more likely to have undesirable odors than other gasolines. Over 3,000,000 barrels of gasoline have been made in a single year by the Burton "cracking" process. Future gasoline supplies must necessarily be largely "cracked" gasolines.

Casing-head gasoline is made by compression of natural gas with accompanying refrigeration or absorption in petroleum distillates. The straight casing-head gasoline is never used alone, on account of its high volatility and high cost, but is used to blend with distillates too heavy to use alone for motor fuels. About 10 per cent. of the present production of gasoline is blended casing-head gasoline. By blending a "blended casing-head gasoline" with other gasolines a suitable range of boiling points is secured.

The difference in power possible from different gasolines is negligible provided the gasoline is burned completely in the motor, and the gasolines with a high percentage of volatile constituents and no "tailings" or heavy oil are easiest to burn completely. The low boiling-point constituents of the gasoline aid particularly in starting, but the evaporation loss is greater and the price of the gasoline is higher where excessive amounts of these light oils are present. The best gasolines have a large percentage of medium boiling constituents.

The following analyses of gasolines were made by the author in 1911. Ninety-seven per cent. was recovered in the distillation which was made from an Engler flask at the rate of 10 cc. per minute.

Sample No.	1	2	3	4	5	6	7	8	9	10
Gravity (°B.)	60.5	60.0	65.5	62.0	62.8	60.4	61.5	62.8	59.1	64.3
Boiling pt. (°C.)	85	80	90	91	86	80	60	68	78	82
Distillate to 100°C.	16	26	69	36	36	26	56	38	20	42
" " 120°C.	71	64	92	67	77	71	87	73	65	76
" " 140°C.	89	87	97	85	92	91	94	91	88	92

In connection with the tables on pages 209-210 (Bureau of Mines Tech. Paper No. 163) it may be noted that the uncracked gasolines gave iodine numbers from 0.6 to 6.5 and straight cracked gasolines gave iodine numbers of 20 to 60. Blended gasolines containing cracked gasolines gave iodine numbers above 8 or 10. The iodine number is a measure of the unsaturated hydrocarbons present, but the amount of unsaturated hydrocarbons can also be determined roughly by shaking 20 cc. of gasoline with 20 cc. of sulphuric acid (1.84 specific gravity, or 94 per cent.) and noting the amount of gasoline absorbed. Gasolines consisting largely of cracked distillates gave absorptions of 3 per cent. to 6 per cent.

Volatility is the most important property of a gasoline since vaporization in the motor is necessary. The test which gives the most information is distillation from an Engler flask of 100 cc. capacity, distillation being conducted at the rate of two drops per second (4 to 5 cc. per minute) using an ice-cooled condenser, and noting the temperatures at which each 10 per cent. is distilled, particularly the temperatures at which 20 per cent. and 90 per cent. are distilled, and the temperature at which the distillation is complete. The rate of heating is important to get the best results. The value of the distillation test lies in the fact that it gives a direct measure of the vaporizing power of the gasoline.

SOME ANALYSES OF GASOLINES

Sold During 1915

(Tables from Bureau of Mines Tech. Paper No. 163, pp. 17–18.

Results of tests showing volatility ranges of typical "straight" refinery gasolines from Eastern, Mid-continent, and California fields.

Sample No.	Commercial rating of gasoline (°B.)	Actual gravity as determined by test		Percentage distilled at temperatures of—					
		Specific gravity	°B.	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.
	EASTERN GASOLINE.								
12	(*a*)	0.736	60.2	1.2	4.4	20.0	59.0	87.3	99.3
13	68° to 70°.....	0.718	65.0	3.5	15.0	39.2	72.9	91.5	99.5
14	76°	0.699	70.3	7.2	33.0	69.7	91.2	—	—
	MID-CONTINENT GASOLINE.								
37	58° to 60°.....	0.745	57.9	1.7	7.4	21.2	50.9	79.4	93.6
38	60° to 62°.....	0.727	62.6	3.3	14.6	41.4	68.2	87.3	96.4
39	68° to 70°.....	0.703	69.2	8.6	34.4	70.4	91.2	—	—
	CALIFORNIA GASOLINE.								
49	....	0.749	56.9	3.0	12.6	51.1	81.9	94.3	—
50	....	0.733	61.0	3.8	16.1	45.5	71.8	94.1	—

(*a*) Rated as "motor" gasoline.

Results showing specific gravity and volatility ranges of blended casing-head and "straight" refinery gasolines from the eastern markets.

Sample No.	Commercial rating (°B.)	Actual gravity as determined by test		Percentage distilled at temperatures of—					
		Specific gravity	°B.	Up to 50 °C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.
	BLENDED CASING-HEAD GASOLINE.								
15	60° to 65°.....	0.733	61.0	7.9	16.8	33.2	56.6	78.5	93.5
16	68° to 70°.....	0.706	68.3	16.7	32.1	53.0	75.1	88.2	—
17	76°	0.687	73.8	30.8	49.1	64.4	78.1	88.8	—
	"STRAIGHT" REFINERY GASOLINE.								
1	60° to 65°.....	0.724	63.4	0.0	2.2	33.8	75.5	94.4	—
2	68° to 70°.....	0.703	69.2	3.5	27.6	67.5	90.6	99.1	—
3	74° to 76°.....	0.684	74.7	14.5	46.2	78.3	95.1	—	—

Results showing calorific value, power developed in engine tests, specific gravity, and percentage of sulphur in various typical gasolines from Mid-continent and Eastern fields.

Sample No.	Field from which sample was obtained	Process of manufacture	Gravity		Calorific value of gasoline		Power developed, horse-power-hours per lb. of gasoline.	Sulphur content
			Specific gravity	°B.	Calories per gram.	B. t. u. per pound		Per cent.
22	Mid-continent	Cracking plant	0.745	57.9	11,165	20,097	1.345	0.02
26	do	"Straight" refinery	0.742	58.7	11,174	20,113	1.403	0.01
43	do	do	0.733	61.0	11,180	20,124	1.350	0.05
13	Eastern	do	0.718	65.0	11,187	20,137	1.405	0.04
19	Mid-continent	do	0.724	63.4	11,215	20,187	1.395	0.05
38	do	do	0.727	62.6	11,221	20,198	1.396	0.03
15	Eastern	Blended casing-head	0.733	61.0	11,230	20,214	1.376	0.03
1	do	"Straight" refinery	0.724	63.4	11,236	20,225	1.420	0.03
34	Mid-continent	do	0.715	65.8	11,250	20,250	1.365	0.02
9	Eastern	do	0.687	73.8	11,315	20,367	1.487	0.02

The gravity test is the most widely used commercial test. It gives indications of value and is easily made.

Proposed Specifications for Motor Gasoline.—(Bureau of Mines Tech. Paper, No. 166, p. 19.)

Color. Requirement.—Water white.

Method of Determination.—Inspection of column in 4-ounce sample bottle.

Acidity. Requirement.—Total absence.

Method of Determination.—Ten cc. of the gasoline is to be shaken thoroughly with 5 cc. of distilled water. The aqueous extract must not color blue litmus pink.

Volatility. Requirements.—The gasoline shall, when distilled by the method described hereafter, meet the following requirements:

(*a*) The temperature read on the thermometer when 20 per cent. has distilled shall not be below 70° C. (158° F.) nor above whatever limit is fixed after due consideration of conditions of use.

(*b*) The temperature read when 90 per cent. has distilled shall not be above another limit similarly chosen.

(*c*) The temperature read when 50 per cent. has distilled shall not be higher than a mark half way between the 20 per cent. and the 90 per cent. limit.

(*d*) The dry point shall not exceed the actual 90 per cent. reading by more than 55° C. (99° F.).

Tolerance.—If either the 20 per cent. or the 90 per cent. temperature mark is above the required limit by an amount not exceeding 10° C. (18° F.), the gasoline may be considered acceptable if the sum of the two temperatures read for the 20 and the 90 per cent. marks do not exceed the sum of the adopted limits.

(The distillation method and apparatus are minutely described. The Engler flask is used with 100 cc. of gasoline and the heat applied so that 4 to 5 cc. distil per minute.)

Gasoline for Special Uses.—Gasoline, for use as a solvent where the gasoline is recovered, should be free from heavy boiling constituents, that is, have a low end point on distillation. Also gasoline for cleaning purposes should be volatile and free from "tailings" as shown by distillation.

For actual specifications of commercial gasoline, see Index.

Fuel Oils.—For specifications, see Index. For the calorific power of liquid fuels of different specific gravities see Sherman and Kropff, *J. Am. Chem. Soc.*, pp. 1626-1631 (1908).

CHAPTER XXVII.

KEROSENE.

Kerosene usually distils between 150° and 300° C. (302° to 572° F.) under atmospheric pressure, and has a gravity of 42° to 47° Bé. For general illuminating purposes, kerosene should be free from very light oils as shown by the flash test, free from heavy oils as shown by the distillation test, and free from sulphur and other encrusting substances as shown by a prolonged burning test.

The flash test is usually taken with the Tagliabue open cup, the best grade of oil being called "150° fire test" "water white" oil. The oil is sold largely by fire test, Baumé gravity and color.

Many States have inspection laws, usually for safety only, and specify the flash test in the open or closed cup. The flash test at 100° F. in the Elliott closed cup (so-called New York State Board of Health tester) is specified in a number of states, with or without a gravity requirement. The flash point in the Elliott closed cup is, for kerosene, some 21° F. lower than the Tagliabue flash test (open cup), and 41° F. lower than the Tagliabue fire test.

The author takes this opportunity to put in more accessible form some results of analyses made by him (Supp. Bull. of the N. C. Dept. of Agri., Sept., 1910; Sept., 1911; and June, 1912). The following is from the *Bulletin* for 1910:

"A comparison of 58 oils was made after classifying on the basis of 6 per cent. residue after distillation by the continuous Engler method:

Residue at 570°F.	Less than 6%	More than 6%
Number of oils tested	20	38
Candle-power (after ½ hour)	7.91	7.62
Candle-power (after 7½ hours)	7.10	6.23
Drop in candle-power (%)	10.2	18.6
Viscosity at 68°F. (Engler)	1.11	1.17

"Of the low-residue oils only one gave as much as 15 per cent. drop in candle-power. Of the 38 high-residue oils 58 per cent. gave more than 15 per cent. drop in the 7 hours.

"The photometric method was similar to that recommended by the International Committee. Glass lamps were used. The reservoirs were cylindrical with flat bottoms and held about 325 cc. The initial oil level was 6 cm. below the top of the wick tube and the drop in oil level was usually 40 mm. (1.6 in.) during the total burning period of 7½ hours. A No. 1 "Model" burner and Macbeth chimney No. 502 were used. New American wicks, recently dried for 1 hour at 110° C. were used each time. The lamps were allowed to stand over night after filling and trimming.

"The illuminating power was determined after burning ½ hour and again 7 hours later. During the first ¼ hour after lighting the flames were turned up to the highest safe limit and were not again disturbed. The oil was kept at a constant temperature of 80° to 85° F. by immersing in running water. Usually about 40 cc. of oil remained in the lamp at the last measurement. The measurements were made with a Reichsanstalt photometer using a standardized Hefner lamp. The Hefner unit was taken as equal to 0.90 candle-power and never varied more than 0.5 per cent. on account of humidity. Each reading was made five times Many of the photometric tests were made in duplicate.

"The oils analyzed were chosen on account of some special feature, such as marked color, high or low viscosity, high specific gravity, etc., or, as in a number of cases, simply to get a sample of as many brands as possible.

"Only 17 per cent. of the 134 samples passing the flash test gave any distillate below 150° C. Seven oils gave less than 15 per cent. distillate below 200° C. Six others gave from 15 to 19 per cent. distillate below 200° C. Eight oils gave more than 40 per cent. distillate below 200° C." (The flash test requirement was 100° F. flash, or over, in the Ellicott closed cup.)

As a result of the above tests, a residue requirement was adopted by the State of "not more than 6 per cent. by weight of residue remaining undistilled at 570° F. * * * except that oils of not less than 47° Bé. at 60° F. shall not contain more than 10 per cent. of residue by weight."

It is interesting to note that subsequent tests (reported Sept., 1911) of 41 different samples, representing over 30 different brands of kerosene, only four showed as much as 15 per cent. drop in candle-power in 12 hours' burning, the maximum drop being 24.8 per cent. in 12 hours, against 65.1 per cent. maximum drop for the 7 hours in the first series. Also two of these four bad oils had 6 per cent. and 8.9 per cent. residue undistilled

at 570° F. The method of making the burning test in this case was as follows: "The candle-power was measured at the end of the first and twelfth hours after lighting, using as a comparison light a standard electric bulb at 4 watts per candle-power. The lamp had a glass reservoir of 600 cc. capacity and was fitted with a No. 1 sun-hinge burner and a No. 27 Macbeth chimney. No. 1 American wicks recently dried were allowed to soak in the oil over night. The oil level dropped 30 millimeters during the burning period. Over 150 cc. of oil remained at the end of each test. Duplicate tests were made on most of the samples. The Marcy patent burner was found unsuited for this work unless a much longer burning period were adopted."

"With the exception of one sample, the distillation began at 150° to 160° C. and the distillate below 200° C. varied from 26 per cent. to 45 per cent." After the adoption of the 6 per cent. residue test, the minimum amount of oil distilling below 250° C. increased from 39 per cent. to 68 per cent., the maximum being 85 per cent.

Five of the 41 oils gave more than 0.050 per cent. of sulphur. The amount of sulphur varied from 0.001 per cent. to 0.086 per cent., the sulphur being determined gravimetrically after burning the oil and wick completely.

Cracked oils may be shown by the iodine number. The Hanus iodine number for a 1-gram sample was from 7.2 to 25.2.

The viscosity can be used as a quick means for locating oils which would have high residues at 570° F. The Engler-Ubbelohde viscosimeter for illuminating oils was found more suitable for this work than the regular Engler apparatus. Before adoption of the 6 per cent. residue requirement, viscosities ran as high as 1.26 Engler; afterwards the range was from 1.07 to 1.13, the average being slightly below 1.09. (1.07 to 1.13 Engler is equivalent to 1.39 to 1.63 Engler-Ubbelohde viscosity.) Low viscosity oils never show high residues on distillation.

Suggestions for Specifications.—(*a*) *Safety.*—Take the flash point with the Elliott closed cup or with the Abel-Pensky apparatus. Sufficient safety will be attained by 95° to 100° F. flash in these cups, or 140° to 150° F. fire test in the open cup. There

is no advantage in specifying both flash test and fire test, nor should a minimum boiling point, or a maximum distillate to a given temperature, ordinarily be specified.

(*b*) *Degree of Refining.*—The oil should be well-refined and water white. A well-refined oil will not usually have as much as 0.04 per cent. sulphur and will not show a marked color when shaken for two minutes with sulphuric acid of 1.73 specific gravity. As the burning test for a long period will show the practical degree of refining, by the amount of encrustation on the wick, no extended tests for refining are usually necessary.

(*c*) *Inherent Character of the Oil.*—The oil will be distilled from an Engler flask at the rate of two drops per second, attention being paid to the quantity distilling below 200° and 250° C. (The best oils give over 30 per cent. distillate at 200° and over 75 per cent. distillate at 250° C. when distilled at the rate of two drops per second.) The residue must not exceed 5 per cent. by weight at 300° C., except that oils of over 46.5° Bé. may show up to 8 per cent. of such residue. Large amounts of the lighter oils improve the candle-power and the burning qualities. "Cracked" oils are not desired, so the Hanus iodine number should be below 15 on a 1-gram sample. The gravity must not be below 42° Bé.

(*d*) *Burning Quality.*—The oil must not show more than a specified drop in candle-power (12 per cent.), or drop in flame height (¼ inch), under specified conditions of burning for a period of 24 to 72 hours. The condition of the flame as well as its size will be noted at the end of the burning test and no hard ash, crust, gum or cinders shall have formed on the wick. A long burning period with the burner to be used in service gives the most information. Ordinarily a photometric test will not be necessary as a drop of 10 to 15 per cent. in candle-power is readily apparent to the eye. The distillation test and the burning test will be given special weight.

For specifications of kerosene and other burning oils, see Index.

Kerosene for kerosene engines, such as tractor engines, etc., is usually burned by preheating the fuel charge before admission

into the cylinder. Sometimes steam is introduced with the charge so as to facilitate combustion and to keep the cylinder clean. By preheating the charge of kerosene, vaporization is more nearly complete, though part of the kerosene remains as a finely atomized liquid and is burned rather than exploded. The explosion range for kerosene vapor mixed with air is much lower than with gasoline vapor and air, consequently the carburetor must be more carefully adjusted in order to give the proper explosive mixture.

CHAPTER XXVIII.

TABLES.

1. Viscosity Tables, Showing Relation of Saybolt Time to Engler Number.

2. Tables for Converting Baumé Gravity to Specific Gravity, Etc.

3. Table Showing Baumé Gravity Corrections for Temperature Above 60° F.

4. Table of Centigrade and Fahrenheit Degrees.

5. Wholesale Prices of Oils and Heavy Chemicals.

6. Petroleum Statistics.

Viscosity Tables.

Showing the relation of Saybolt Time to Engler Number. Calculated from work done at the Bureau of Standards by Dr. C. W. Waidner. (*Cf. Proc. Am. Soc. Test. Mat.*, 15, p. 284, 1915, and Tables by McIlhiney, *J. Ind. & Eng. Chem.*, 8, p. 434, 1916.)

Note:—These tables are sufficiently accurate for most commercial purposes. They are offered as being the latest and the best available until the publication of further work by the Bureau of Standards on the standardization and comparison of the two viscosimeters.

Universal Saybolt time (Sec.)	Engler Number (H_2O = 1.)	Saybolt	Engler	Saybolt	Engler	Saybolt	Engler	Saybolt	Engler	Saybolt	Engler
40	1.32	83	2.36	126	3.44	169	4.54	213	5.69	257	6.85
41	1.35	84	2.39	127	3.46	170	4.56	214	5.71	258	6.88
42	1.37	85	2.41	128	3.49	171	4.59	215	5.74	259	6.91
43	1.40	86	2.44	129	3.51	172	4.62	216	5.77	260	6.94
44	1.42	87	2.46	130	3.54	173	4.64	217	5.79	261	6.96
45	1.45	88	2.49	131	3.56	174	4.67	218	5.82	262	6.99
46	1.47	89	2.51	132	3.59	175	4.69	219	5.85	263	7.01
47	1.50	90	2.54	133	3.61	176	4.72	220	5.87	264	7.04
48	1.52	91	2.56	134	3.64	177	4.75	221	5.90	265	7.07
49	1.55	92	2.59	135	3.67	178	4.77	222	5.93	266	7.09
50	1.57	93	2.61	136	3.69	179	4.80	223	5.95	267	7.12
51	1.59	94	2.64	137	3.72	180	4.82	224	5.98	268	7.15
52	1.62	95	2.66	138	3.74	181	4.85	225	6.01	269	7.17
53	1.64	96	2.69	139	3.77	182	4.88	226	6.03	270	7.20
54	1.67	97	2.71	140	3.79	183	4.90	227	6.06	271	7.23
55	1.69	98	2.74	141	3.82	184	4.93	228	6.09	272	7.25
56	1.72	99	2.76	142	3.85	185	4.95	229	6.12	273	7.28
57	1.74	100	2.79	143	3.87	186	4.98	230	6.14	274	7.31
58	1.76	101	2.81	144	3.90	187	5.01	231	6.17	275	7.33
59	1.79	102	2.84	145	3.92	188	5.03	232	6.19	276	7.36
60	1.81	103	2.86	146	3.95	189	5.06	233	6.22	277	7.39
61	1.84	104	2.88	147	3.97	190	5.08	234	6.25	278	7.41
62	1.86	105	2.91	148	4.00	191	5.11	235	6.27	279	7.44
63	1.88	106	2.93	149	4.02	192	5.13	236	6.30	280	7.47
64	1.91	107	2.96	150	4.05	193	5.16	237	6.33	281	7.49
65	1.93	108	2.99	151	4.08	194	5.19	238	6.35	282	7.52
66	1.95	109	3.01	152	4.10	195	5.21	239	6.38	283	7.55
67	1.98	110	3.04	153	4.13	196	5.24	240	6.41	284	7.57
68	2.00	111	3.06	154	4.15	197	5.26	241	6.43	285	7.60
69	2.03	112	3.09	155	4.18	198	5.29	242	6.46	286	7.63
70	2.05	113	3.11	156	4.20	199	5.31	243	6.48	287	7.65
71	2.07	114	3.14	157	4.23	200	5.34	244	6.51	288	7.68
72	2.10	115	3.16	158	4.25	201	5.37	245	6.53	289	7.71
73	2.12	116	3.19	159	4.28	202	5.39	246	6.56	290	7.73
74	2.14	117	3.21	160	4.30	203	5.42	247	6.58	291	7.76
75	2.17	118	3.24	161	4.33	204	5.45	248	6.61	292	7.79
76	2.19	119	3.26	162	4.36	205	5.47	249	6.64	293	7.81
77	2.22	120	3.29	163	4.38	206	5.50	250	6.67	294	7.84
78	2.24	121	3.31	164	4.41	207	5.53	251	6.69	295	7.87
79	2.27	122	3.34	165	4.43	208	5.55	252	6.72	296	7.89
80	2.29	123	3.36	166	4.46	209	5.58	253	6.75	297	7.92
81	2.31	124	3.39	167	4.49	210	5.61	254	6.77	298	7.95
82	2.34	125	3.41	168	4.51	211	5.63	255	6.80	299	7.97
						212	5.66	256	6.83	300	8.00

To change higher Saybolt time to Engler numbers multiply Saybolt time by 0.0267. To change higher Engler numbers to Saybolt time multiply Engler numbers by 37.5. To change Saybolt time to Redwood time multiply Saybolt time by 0.84 (accurate for oils with viscosity above 100 Saybolt.)

TABLE FOR CONVERTING BAUMÉ GRAVITY TO SPECIFIC GRAVITY, ETC.
(Calculated from Bureau of Standards Circular No. 57; based on the formula:

$$\text{Sp. gr. at } 60^\circ \text{ F} = \frac{140}{130 + \text{deg. Bé.}}).$$

Degrees Baumé (Modulus 140).	Specific gravity 60°/60°F.	Pounds per gallon	Gallons per pound	Degrees Baumé (Modulus 140).	Specific gravity 60°/60°F.	Pounds per gallon	Gallons per pound
10.0	1.0000	8.328	0.1201	50.0	0.7778	6.476	0.1544
11.0	0.9929	8.269	0.1209	51.0	0.7735	6.440	0.1533
12.0	0.9859	8.211	0.1218	52.0	0.7692	6.404	0.1562
13.0	0.9790	8.153	0.1227	53.0	0.7650	6.369	0.1570
14.0	0.9722	8.096	0.1235	54.0	0.7609	6.334	0.1579
15.0	0.9655	8.041	0.1244	55.0	0.7568	6.300	0.1587
16.0	0.9589	7.986	0.1252	56.0	0.7527	6.266	0.1596
17.0	0.9524	7.931	0.1261	57.0	0.7487	6.233	0.1604
18.0	0.9459	7.877	0.1270	58.0	0.7447	6.199	0.1613
19.0	0.9396	7.825	0.1278	59.0	0.7407	6.166	0.1622
20.0	0.9333	7.772	0.1287	60.0	0.7368	6.134	0.1630
21.0	0.9272	7.721	0.1295	61.0	0.7330	6.102	0.1639
22.0	0.9211	7.670	0.1304	62.0	0.7292	6.070	0.1647
23.0	0.9150	7.620	0.1313	63.0	0.7254	6.038	0.1656
24.0	0.9091	7.570	0.1321	64.0	0.7216	6.007	0.1665
25.0	0.9032	7.522	0.1330	65.0	0.7179	5.976	0.1673
26.0	0.8974	7.473	0.1338	66.0	0.7143	5.946	0.1682
27.0	0.8917	7.425	0.1347	67.0	0.7107	5.916	0.1690
28.0	0.8861	7.378	0.1355	68.0	0.7071	5.886	0.1699
29.0	0.8805	7.332	0.1364	69.0	0.7035	5.856	0.1708
30.0	0.8750	7.286	0.1373	70.0	0.7000	5.827	0.1716
31.0	0.8696	7.241	0.1381	71.0	0.6965	5.798	0.1725
32.0	0.8642	7.196	0.1390	72.0	0.6931	5.769	0.1733
33.0	0.8589	7.152	0.1398	73.0	0.6897	5.741	0.1742
34.0	0.8537	7.108	0.1407	74.0	0.6863	5.712	0.1751
35.0	0.8485	7.065	0.1415	75.0	0.6829	5.685	0.1759
36.0	0.8434	7.022	0.1424	76.0	0.6796	5.657	0.1768
37.0	0.8383	6.980	0.1432	77.0	0.6763	5.629	0.1776
38.0	0.8333	6.939	0.1441	78.0	0.6731	5.602	0.1785
39.0	0.8284	6.898	0.1450	79.0	0.6699	5.576	0.1793
40.0	0.8235	6.857	0.1459	80.0	0.6667	5.549	0.1802
41.0	0.8187	6.817	0.1467	81.0	0.6635	5.522	0.1811
42.0	0.8140	6.777	0.1476	82.0	0.6604	5.497	0.1819
43.0	0.8092	6.738	0.1484	83.0	0.6573	5.471	0.1828
44.0	0.8046	6.699	0.1493	84.0	0.6542	5.445	0.1837
45.0	0.8000	6.661	0.1501	85.0	0.6512	5.420	0.1845
46.0	0.7955	6.623	0.1510	86.0	0.6482	5.395	0.1854
47.0	0.7910	6.586	0.1518	87.0	0.6452	5.370	0.1862
48.0	0.7865	6.548	0.1527	88.0	0.6422	5.345	0.1871
49.0	0.7821	6.511	0.1536	89.0	0.6393	5.320	0.1880

NOTE:—Another hydrometer widely used in the oil trade is based on a different formula: $\text{Sp. gr. at } 60^\circ\text{F.} = \frac{141.5}{131.5 + \text{deg. Bé.}}$. Such readings are too high by 0.1° to 0.2° Bé. for lubricating oils, 0.3° to 0.4° Bé. for kerosene and 0.5° to 0.7° Bé. for gasolines.

TABLE SHOWING BAUMÉ GRAVITY CORRECTIONS FOR TEMPERATURES ABOVE 60°F. (Compiled from Bureau of Standards Circular No. 57.)

This table gives the corrections to be subtracted from the observed degrees Baumé of lubricating oils, etc., to obtain the true degrees Baumé at 60°F. (modulus 140.)

Observed temperature	Observed Degrees Baumé										
	16	18	20	22	24	26	28	30	32	34	36
	Subtract from observed degrees Baumé to give true degrees Baumé at 60° F.										
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
66	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
68	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
70	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8
72	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.9
74	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.1
76	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2
78	0.9	0.9	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4
80	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5
82	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6
84	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.7	1.8
86	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8	1.9
88	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0
90	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1
92	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3
94	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4
96	1.9	1.9	2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5
98	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.6	2.7
100	2.1	2.2	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.7	2.8
105	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2
110	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5
115	2.9	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.8	3.9
120	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2

NOTE:—The corrections for temperatures *below* 60° F. are in the same proportion for lubricating oils as shown for temperatures *above* 60° F., but in this case the correction is to be added.

TABLE OF CENTIGRADE AND FAHRENHEIT DEGREES.

$$\text{Temp. Fahr.} = \frac{9}{5} \times \text{temp. C.} + 32^\circ.$$

$$\text{Temp. C.} = \frac{5}{9}\,(\text{temp. F.} - 32^\circ).$$

°C.	°F.	°C.	°F.	°C.	°F.
—40	—40	100	212	250	482
—35	—31	105	221	255	491
—30	—22	110	230	260	500
—25	—13	115	239	265	509
—20	— 4	120	248	270	518
—15	+ 5	125	257	275	527
—10	14	130	266	280	536
— 5	23	135	275	285	545
0	32	140	284	290	554
+ 5	41	145	293	295	563
10	50	150	302	300	572
15	59	155	311	305	581
20	68	160	320	310	590
25	77	165	329	315	599
30	86	170	338	320	608
35	95	175	347	325	617
40	104	180	356	330	626
45	113	185	365	335	635
50	122	190	374	340	644
55	131	195	383	345	653
60	140	200	392	350	662
65	149	205	401	355	671
70	158	210	410	360	680
75	167	215	419	365	689
80	176	220	428	370	698
85	185	225	437	375	707
90	194	230	446	380	716
95	203	235	455	385	725
		240	464	390	734
		245	473	395	743
				400	752

By noting that 5° C. are exactly equal to 9° F., and that the above figures are all even numbers (not rounded off) the exact temperature can be readily read for either thermometer.

Wholesale Prices of Oils and Heavy Chemicals.

Compiled from New York market quotations as given in the *Oil, Paint & Drug Reporter*. On account of the high prices prevailing, prices are also given for normal conditions.

	June 23, 1917	August 1, 1914
Mineral Lubricating Oils:		
Black, reduced, 29°B., 25-30° cold test, gal.	13½-14	13½-14
" " 29°B., 15° C. T.	14 -15	14 -14½
" " summer	13 -14	13 -13½
Cylinder, light filtered	21 -26	21½-33
" dark filtered	18 -19	18 -26
" extra cold test	26 -31	27 -34
" dark steam refined	15 -19	14½-25
Neutral, West Virginia, 29 gravity	10¾-14¾	23 -23½
" 32-34 gravity, bloomless	21½-22	18 -19
" 31 gravity, wool grade	19½-20	16 -16½
Paraffin, high viscosity	29½-30	27 -28
" 903 sp. gr.	21½-22	15 -15½
" 865 sp. gr.	18½-19	12½-13
" Red	18 -19	15 -16
Spindle, No. 200	24 -25	18 -19
" No. 160	23½-24	17 -18
" No. 110	23 -23½	16 -17
" No. 80	21 -22	14 -15
" filtered	28 -35	21. -22
Animal Oils:		
Degras, foreign and domestic, lb.	9¾-10	3 - 3½
Horse	17 -18	6 - 7
Lard, prime winter, gal.	1.90-	92 -93
" extra No. 1	1.47-1.49	62 -63
" No. 2	1.43-1.45	51 -52
Neatsfoot, 20 deg.	1.70-	96 -98
" prime	1.55-1.60	64 -65
Red, saponified, lb.	15 -15½	6¾- 7
Stearic acid, single press	23 -24	8¾-10½
Tallow, acidless, gal.	1.51-1.55	64 -65
" prime	1.46-1.50	62 -63
Fish Oils:		
Cod, domestic, gal.	86 -88	32 -34
Menhadin, light, strained	90 -92	37 -38
Sperm, bleached, winter, 38° C. T	1.32-1.33	70 -
Porpoise, body	80 -85	40 -45
Whale, natural, winter	93 -95	48 -
Vegetable Oils:		
Castor, No. 3., lb.	22 -23	8 - 8½
Cocoanut, Cochin, imported	21 -22	10½-11½
Corn, crude, in barrels, 100-lbs.	15. -15.25	6.35-6.40
Cottonseed, crude, f. o. b. mills, gals.	1.10-	41 -42
" prime summer yellow, 100-lbs.	16.40-	6.50-6.75
Linseed, raw, car-lots, gal.	1.17-	59 -
" boiled, car-lots	1.18-	60 -
Olive, denatured	1.65-1.75	78 -82

WHOLESALE PRICES OF OILS AND HEAVY CHEMICALS. (*Continued.*)

	June 23, 1917	August 1, 1914
Vegetable Oils: (*Continued.*)		
Olive, foots, lb.	19 -20	7 - 7½
Palm, Lagos, spot	18 -18½	7 - 7¼
Peanut, crude, f. o. b. mill, gal.	1.15-1.20	62 -68
Rapeseed, refined	1.45-1.50	59 -
" blown	1.50-1.55	63 -
Rosin oil, first rectified	— -36	— -27
" " fourth rectified	— -66	— -60
Soya bean, Manchuria, spot, barrels (lb.)	14½-15	6¼-
Grease, Naval Stores, Etc.		
Grease, white	17	10½-
" brown	15 -15½	5½- 6½
Lard, Middle West	21 -21.1	10 -37
Tallow, special, loose	17¼-	— - 6⅛
Rosin, common to good strained, 280-lbs.	6.15-	4 -4.10
Spirits of turpentine, gal.	43 -	47½-48
Chemicals, Heavy:		
Acid, sulphuric, 66°, 100-lbs	1.50-2.25	1. -1.10
Soda ash, light 58%, in bags	2.65-3.05	0.57½-0.62½
Soda, caustic, 76-78% in drums	6.75-6.87½	1.42½-1.47½
Potash, caustic, 88-92%, lb.	84 -86	4½

PETROLEUM STATISTICS.

(From the United States Geological Survey Reports.)

Rank of Petroleum-Producing States based on quantity of oil marketed (1915) with an estimate of production for 1916. (Barrel = 42 gallons.)

State	Rank, 1915	Quantity (barrels) 1915	Percentage 1915	Production (Est.) (barrels) 1916
Oklahoma	1	97,915,243	34.83	105,000,000
California	2	86,591,535	30.81	89,000,000
Texas	3	24,942,701	8.87	26,000,000
Illinois	4	19,041,695	6.77	16,500,000
Louisiana	5	18,191,539	6.47	15,800,000
West Virginia	6	9,264,798	3.30	8,500,000
Pennsylvania	7	7,838,705	2.79	8,000,000
Ohio	8	7,825,326	2.78	7,400,000
Wyoming	9	4,245,525	1.51	6,300,000
Kansas	10	2,823,487	1.00	6,500,000
New York	11	887,778	0.32	900,000
Indiana	12	875,758	0.31	1,000,000
Kentucky	13	437,274	0.16	1,200,000
Colorado	14	208,475	0.08	190,000
Alaska	15	14,265		10,000
Missouri	16			
Michigan	17			
		281,104,104	100.00	292,300,000

PETROLEUM STATISTICS. (*Continued.*)

Rank of Petroleum-Producing States based on value of oil marketed (1915).

States	Rank	Value	Percentage
Oklahoma	1	$56,706,133	31.60
California	2	36,558,439	20.37
Illinois	3	18,655,850	10.40
West Virginia	4	14,468,278	8.06
Texas	5	13,026,925	7.26
Pennsylvania	6	12,431,353	6.93
Louisiana	7	10,804,653	6.02
Ohio	8	10,061,493	5.61
Wyoming	9	2,217,018	1.24
Kansas	10	1,702,891	0.95
New York	11	1,390,325	0.77
Indiana	12	813,395	0.45
Kentucky	13	418,357	0.23
Colorado	14	183,485	0.10
Alaska	15		
Missouri	16	24,295	0.01
Michigan	17		
		179,462,890	100.00

World Production of Crude Petroleum.

Country	Production, 1915		Total production, 1857-1915	
	Barrels of 42 gallons	Percentage of total	Barrels of 42 gallons	Percentage of total
United States	[1]281,104,104	65.73	[1]3,616,561,244	60.09
Russia	68,548,062	16.03	1,690,781,907	28.09
Mexico	32,910,508	7.69	123,270,377	2.05
Dutch East Indies[2]	12,386,808	2.90	148,999,921	2.48
Roumania	12,029,913	2.81	130,012,387	2.16
India	8,202,674	1.92	81,592,385	1.36
Galicia	4,158,899	0.97	136,032,500	2.26
Japan and Formosa	3,118,464	0.73	30,169,622	0.50
Peru	2,487,251	0.58	16,794,223	0.28
Germany	995,764	0.23	13,961,333	0.23
Trinidad	[3]750,000	0.18	2,819,430	0.05
Argentina	516,120	0.12	1,033,121	0.02
Egypt	221,768	0.05	1,308,496	0.02
Canada	215,464	0.05	23,709,074	0.39
Italy	39,548	0.01	842,020	0.01
Other countries	[3]10,000		372,000	0.01
	427,695,347	100.00	6,018,260,040	100.00

[1] Marketed production. [2] Includes British Borneo. [3] Estimated.

PETROLEUM STATISTICS. *(Continued.)*

ACTUAL PRODUCTION AND POSSIBLE FUTURE SUPPLY OF PETROLEUM IN THE UNITED STATES.

The following table was compiled by the U. S. Geological Survey and furnished by the Secretary of the Interior to Congress, Feb., 1916 (See Senate Document 310, and Mineral Resources, 1915, Pt. II of the Geological Survey).

Field	Production, 1859–1915		Possible future production (millions of barrels)
	Millions of barrels	Estimated percentage of total exhaustion	
Appalachian	1,150	70	481
Lima-Indiana	438	93	31
Illinois	251	51	244
Kansas-Oklahoma	617	25	1,874
North Texas	44	8	484
Northwest Louisiana	58	22	124
Gulf coast	236	13	1,500
Colorado	11	65	6
Wyoming-Montana	12	2	540
California	835	26	2,345
	3,652	32	7,629

MINERAL OILS EXPORTED FROM THE UNITED STATES IN 1914 AND 1915.

	1914		1915	
	Quantity (gallons)	Value	Quantity (gallons)	Value
Crude	124,735,553	$ 4,958,838	128,263,069	$4,282,827
Naphtha	209,692,655	25,288,414	281,609,081	33,885,047
Illuminating	1,010,449,253	64,112,772	836,958,665	49,988,597
Lubricating and paraffin	191,647,570	26,316,313	239,678,725	32,459,641
Residuum	703,508,621	19,224,250	812,216,209	22,325,557
	2,240,033,652	139,900,587	2,328,725,749	142,941,669

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